1973

Nicolaus Copernicus, 1473-1973

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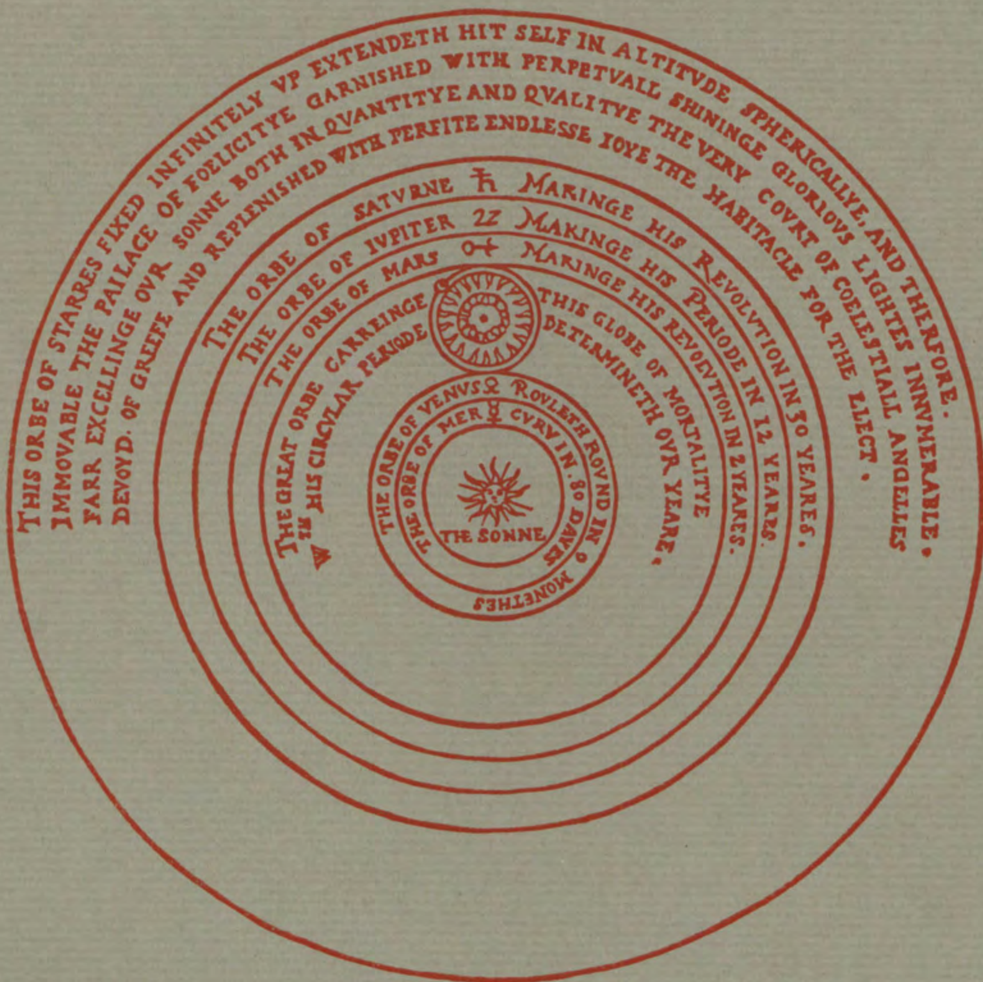

NICOLAUS COPERNICUS ❧ *1473–1973*

Exhibition of Manuscripts & Books : Linderman Library : Lehigh University

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CATALOGUE OF AN EXHIBITION

NICOLAUS COPERNICUS

1473—1973

His *Revolutions* and His Revolution

Catalogue of an Exhibition of Manuscripts & Books

With an Historical Essay by Seymour L. Chapin

LINDERMAN LIBRARY, LEHIGH UNIVERSITY

Bethlehem, Pennsylvania : September–November 1973

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FOREWORD

Nicolaus Copernicus was born at Thorn in Poland on 19 February, 1473. This quincentenary of his birth is being celebrated throughout the world by a wide variety of symposia, conferences and exhibitions. The celebration at Lehigh University takes the form of an exhibit of rare books on the subject of heliocentric Cosmology and Astronomy.

The exhibition contains a number of works by Copernicus, by his predecessors, and by those who followed in his steps. All of the greatest names in the history of Astronomy are represented here. For this magnificent array we are deeply indebted to Dr. Robert B. Honeyman,'20 and Mrs. Honeyman, who have so graciously lent these books from their private collection. For the textual study of Copernicus, his life and works, we thank Dr. Seymour L. Chapin, Department of History, California State University, Los Angeles, whose efforts have made the present catalogue a work of scholarship. The bibliographical descriptions of the works shown here have been prepared by Mr. Jacob Zeitlin, bookseller and bibliographer par excellence. Both have succeeded admirably.

We also wish to acknowledge the considerable assistance of Dr. Owen Gingerich of the Smithsonian Observatory, Cambridge, and of Mr. Charles Eames in supplying information and some of the illustrations used in this catalogue.

We are privileged to mount this exhibit and to share it with you.

JAMES D. MACK
Director of University Libraries

COPERNICUS:

His *Revolutions* and His Revolution

FEBRUARY 19, 1973 marked the 500th anniversary of the birth of Nicolaus Copernicus, whose monumental *De revolutionibus orbium coelestium libri vi* initiated changes so fundamental as to have traditionally been deemed revolutionary. Those changes were not effected overnight; few of his contemporaries appreciated his contributions. And among our contemporaries are to be found many historians of science who, not without justification, have been, if not equally chary of bestowing praise, at least quite reserved in their evaluation of his work. Still, the fact that this quincentenary is being celebrated by symposia, colloquia, and displays all over the western world attests to the strength–and the basic correctness–of the tradition. This exhibit of books, most of them now quite rare, from the collections of Dr. and Mrs. Robert B. Honeyman and Lehigh University is but one attempt to explore and explain the shift in the bases of thought begun by the canon of Frauenburg. Although that shift had ramifications far beyond the area of astronomical theory, it is as a motivator of a progressive movement in astronomy that the revolution of Copernicus will be treated chiefly–though all too briefly–here.

The goal of astronomical theory from the time of the early Greek philosophers onward has been to provide an explanation of the motions of the various objects in the heavens. This search for "laws" originally included only those objects seen there normally–stars, the sun, moon, and planets–and not occasional interlopers such as comets and meteors. Of these, some display great regularity while others contain deviations therefrom. Theoretical advances were provoked more by the latter than by the former.

The most regular of these motions are those of the stars, which seem to complete a westward rotation about the earth once in every twenty-four hours. The most obvious explanation of this phenomenon is to assume that these stars somehow swing around a stationary earth. Add to this the assumption of sphericity, both of the earth and the heavens, and one arrives at a workable conceptual scheme which may have been entertained by Pythagoras. Among his disciples, however, there were those who felt it objectionable that the entire heavens should thus revolve and who, therefore, proposed that it was a movement of the earth from west to east–first orbitally around a central fire (not the sun) and then rotationally around its own axis (with the central fire contained within the earth)–which made the stars *appear* to move. Although this idea appealed philosophically to those who thought the sphere of the stars more noble than this earthly site of change and corruption and thus destined for immobility, it failed to gain any wide acceptance because it was so obviously in conflict with common sense realization that the earth is not in motion. Thus, although he was greatly influenced by such Pythagorean ideas as the perfection of sphericity and the conviction that the universe is ruled by harmony, the great philosopher Plato returned the earth to a central position and to a static state (though he may have entertained other ideas late in his life).

But Plato was extremely significant in the development of astronomical theory from another standpoint. The Pythagoreans had noted that the other "normal" objects in the heavens–the sun, moon, and planets–were possessed of a motion from west to east against the background of the stars, and had endowed them with separate paths, or spheres, to make that possible. By associating different musical tones with these, this also enabled them–or, at least, Pythagoras himself–to listen to the heavenly "music of the spheres." Unfortunately, however, this simple approach was not able to account for the fact that the predominant eastward motion of the planets was not entirely regular; indeed, so far from regularity was the movement of these "wanderers" that they appeared occasionally to move back upon their courses.

The Pythagorean ideas could not explain these westward or "retrograde" motions against the stellar backdrop. And it was Plato, more than any of his predecessors, who recognized the difficulties in assigning responsibilities for the diversity of the other motions.

1. PLATO. *Timaeus*... Omnia Platonis Opera.

[Venetiis, Aldi, et Andreae Soceri Mense Septembri, 1513.] Greek letter.

There are at least three reasons which make it seem fitting to initiate this exhibit with this work, the most scientific of all of Plato's dialogues and the one containing the most complete sketch of his astronomical system. The first is simply that, because the earlier works of the Pythagoreans and others exist only in fragments or in later commentaries, it does represent the real beginning of astronomical theory. The second is that, while the system it hypothecated employed various principles of harmony and geometrical progression, the inadequacies of that system served, as suggested, to publicize the complexities of the problem of accounting for the motions of the planets. The third reason is even more directly associated with the purpose of this exhibit, for, as will be seen, there can be no question but that a 15th century revival of Platonic thought–note that the publication date of the work on exhibit is 1513–exerted a considerable influence on Copernicus and the Copernican revolution.

It was probably in response to Plato's call for attention to the problem of the planets that Eudoxus put forward the theory of homocentric spheres. Of the twenty-seven geocentric spheres in the Eudoxean system, each of which turned uniformly about an axis, one bore the stars and accounted for their daily motions across the sky, three each were employed to account for the motions (and inclinations) of the sun and the moon, and four each were necessary for the more complicated motions of Mercury, Venus, Mars, Jupiter, and Saturn. The great achievement of this scheme was that it allowed two of the spheres for a given planet to be connected in such a way that the uniform motion of the second would largely cancel the uniform motion of the first, leaving only a back and forth oscillation in a figure 8 curve (called the hippopede or horse-fetter), which, superimposed upon the motion given the planet by the other spheres, accounted for the phenomenon of retrogression.

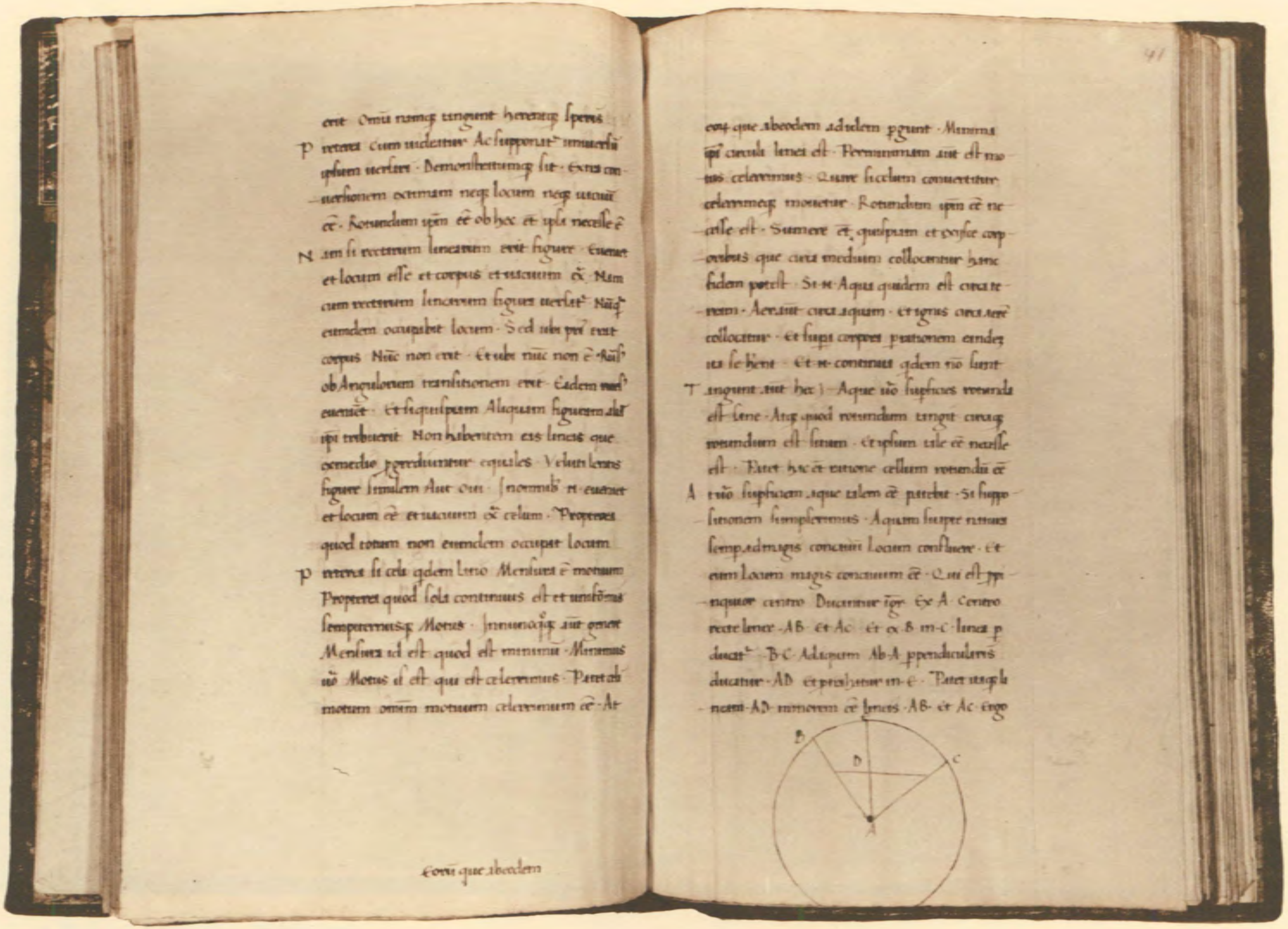
The historical importance of this solution to a basic problem of astronomical theory is that it was completely accepted by Aristotle. Probably because it fitted in so nicely with his physics–and especially with his basic axioms that every celestial motion must be both circular and uniform–Aristotle, in fact, incorporated this system of spheres into the most comprehensive and detailed cosmology developed in the ancient world. Fundamental to that structure was his belief that these spheres, the number of which he more than doubled over that of Eudoxus–who probably thought of them only as mathematical concepts, had an actual material existence.

2. ARISTOTELES. *De coelo et mundo.*

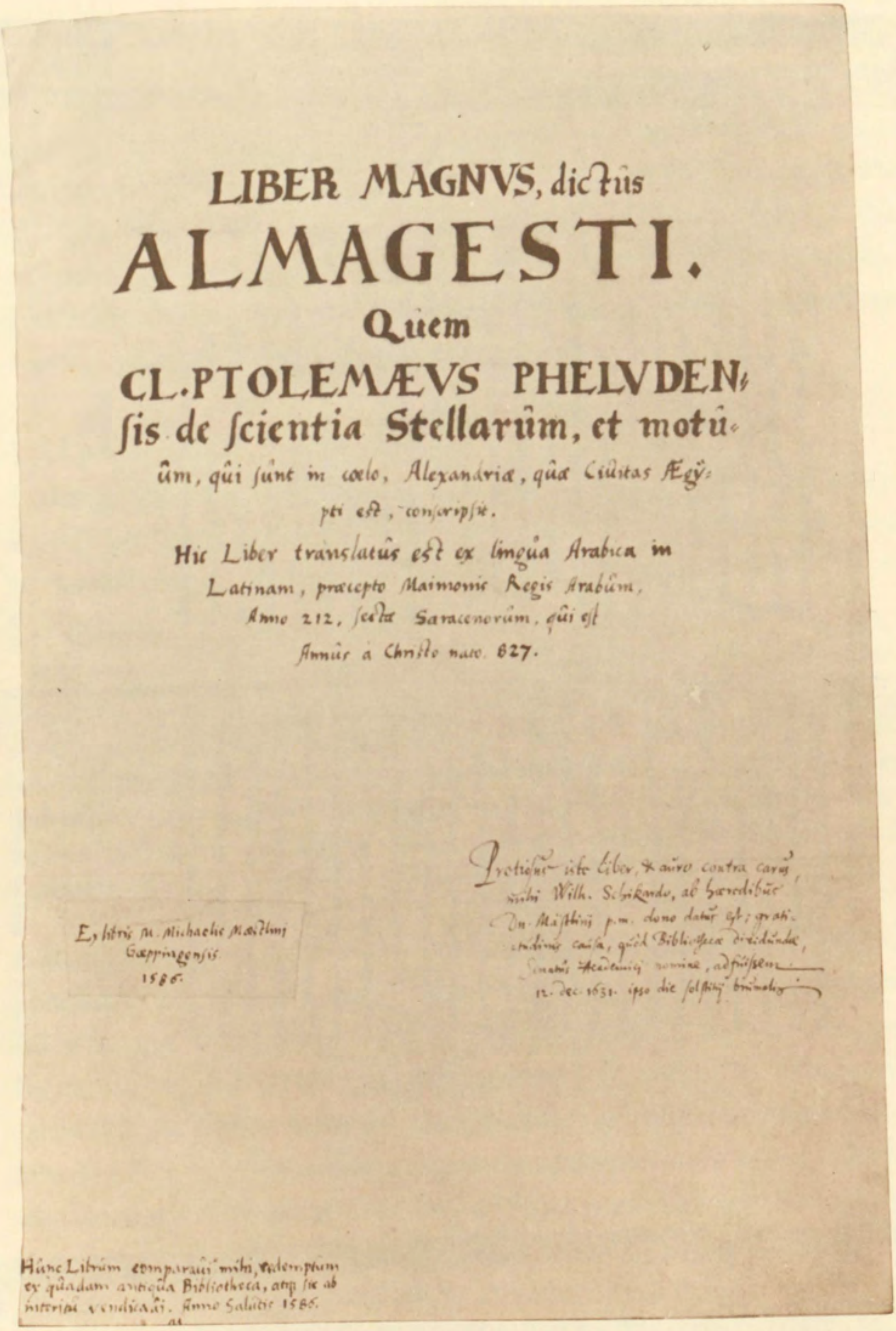
Manuscript. Translated into Latin by Johannes Argyropulus. Vellum. 94 ff. (last 2 blank), 22 x 15 cm. Written *c.* 1460-1470. Ornamental initial within border, heightened in gilt; diagrams. Bound in 19th century blind-stamped dark green calf. Bookplate of the Biblioteca del Principe di Torella.

It is primarily in this work that Aristotle welded together his own physics (and metaphysics) with the homocentric spheres of Eudoxus, whose own writings–as well as those of Callipus, who introduced several additional spheres–are lost. Although this first complete cosmological paradigm was to be partially overthrown by subsequent Greek workers, it was revived and broadly accepted in the medieval west, where it frequently became the object of laborious and beautiful hand-copying–as in the manuscript on display here. It was to be finally dispensed with only as a result of the Copernican revolution.

Although a marvelously unified whole, and, because of that, extremely persuasive and influential, this Aristotelean paradigm did not prove successful in "saving" all the phenomena. A particular problem was its inadequacy for explaining variations in the brightness–and, thus, presumably, in the distances–of the planets from the central earth. The further development of astronomical theory, therefore, required a certain separation of the mathematical treatment from the cosmological framework. This was accomplished in differing ways and with differing degrees of success. Their outcomes influenced all later developments up to and even beyond Copernicus.



2. Aristoteles. *De coelo et mundo*. Manuscript.



4. Ptolemy. *Almagestum*. Manuscript.

4. Ptolemy. *Almagestum*. Manuscript.

One line of attack was to "retrogress" to some of the Pythagorean conceptions. Thus, Heraclides, though he may not have taken it from the Pythagoreans, returned to the idea of a daily rotating earth, but proposed to account for the retrograde motions of Mercury and Venus by orbits centered in the sun and carried by it around the earth. Aristarchus, on the other hand, went even further–becoming the "Copernicus of Antiquity"–and suggested that all of the planets, *including the earth*, moved about a centrally located and stationary sun. That, however, was going too far toward abandoning the common sense observation that Aristotle had raised to the level of cosmological principle. At the same time, these schemes also contained the element of Aristotelean rejection which was to prove amenable to continuing perfection, namely, the discarding of the idea of fixed spheres.

3. ARCHIMEDES. *Psammites* (Sand-reckoner). In: ... Archimedis Syracusani Philosophi Ac Geometrae Excellentissimi Opera omnia. Eutocii Ascalonitae commentaria.

Basileae, Ioannes Heruagius, 1544. Greek and Latin.

Although this work contains some interesting speculations of its own, it has been included here because it is the chief source on the system of Aristarchus, whose own description of it has been lost. Since the copy on exhibit is that contained in the 1544 edition of the works of Archimedes, Copernicus could not have seen this particular version. There is no doubt, however, that he was familiar with this passage and also with commentaries setting forth the views of Heraclides. The Works *of Archimedes did, incidentally, influence Galileo's contribution to the Copernican revolution.*

Although the origin of the calculating device that supplanted homocentric spheres is not known exactly, it is clear that its features were investigated and developed by Apollonius and Hipparchus. In its simplest form the new mechanism for the planets consisted of a small circle, the epicycle, on which a planet rotated uniformly about a point on the circumference of a second rotating circle, the deferent, the center of which coincided with the center of the earth. The proper adjustment of the sizes and rotating rates of these circles provided a simple means for describing such phenomena as retrograde motion–or of avoiding it in the cases of the sun and moon, although it was early realized that this and other effects could be achieved by substituting a mathematically equivalent eccentric circle for that combination. What was even more important, as has been suggested, was that this approach could be almost endlessly modified–by placing epicycles on epicycles or centers of eccentrics on small deferents or even on second, smaller eccentrics–to account for other observed deviations as well as retrogression. A great deal of this modification and elaboration was carried out by Ptolemy, whose *Mathematical Syntaxis* gave a complete quantitative account of all celestial motions in terms of these many moving circles.

4. PTOLEMY. *Almagestum.*

Manuscript. Vellum. 354 pp. 30x21 cm. Written in France [?], 13th century [?]. Ornamental initials, rubricated and astronomical figures throughout. Bound in 16th century red morocco, gilt-ruled, green morocco label, gilt fleurons in spine compartments, g. e. Ownership inscription: "Ex libris M. Michaelis Maestlini Gaeppnigensis 1585."

Due to the fundamental importance of this work, it has been thought appropriate to include it twice. This is the more desirable in view of the fact that the Honeyman collection contains both a manuscript and the first printed copy of this impressive elaboration of the epicyclic theory of Apollonius and Hipparchus, whose treatments are lost. The Latin version manuscript of the century has here been opened to Book III *in which the principles of the epicycle and eccentric are worked out and applied in a presentation of a theory of the sun which, in accordance with Aristotle's axioms, moves that body uniformly about a circle, the epicycle, whose center moves uniformly about another circle, the deferent, with respect to its center.*

There are, however, some things to be noted about this Ptolemaic system in order to prepare for a better understanding of the Copernican contribution. The first, quite simply, is that it was not a "system" at all, but rather a series of individual treatments of the separate planets; despite the general similarity of the methods used for each, there is no mathematical connection between the several models. The second is that Ptolemy, while preserving Aristotle's first axiom of circular motion, violated his second by requiring the rate of rotation of these circles to be uniform not with respect to their geometric centers but with respect to a point displaced therefrom, which he called the equant.

5. PTOLEMY. *Almagestu[m] Cl. Ptolemei... Opus ingens ac nobile omnes Celoru[m] motus continens...*

Venetijs, Petrus Liechtenstein, 10 Jan. 1515.

This first printed edition is probably the Latin version of Gerardus Cremonensis made in the 12th century from an Arabic translation. It has been opened to a point later in the work than the preceding in order to show Ptolemy's departure from the Aristotelean principle to which he had adhered for the sun. In Books V, IX, *and* X, *dealing with the moon and other planets, he introduced, without any forewarning, the equant, a point of uniform angular motion equidistant from the center of the deferent with the earth (in these cases, therefore, the system is geostatic rather than geocentric) but in the opposite direction. Elaborate it was!!*

And, finally, as that last point suggests, Ptolemy set the seal on the post-Aristotelean dichotomy between cosmology and mathematical theory, although considerable confusion reigned on this point up to the time of Copernicus and, indeed, continued to plague interpreters of the Copernican revolution for a long time thereafter.

Ptolemy was the last great exponent of astronomical theory in the Greco-Roman world, or, at least, its last developer; only summaries and commentaries marked the period which saw the breakdown of the ancient Mediterranean unity into three separate entities, the Byzantine Empire, the Islamic world, and Western Europe of the "dark ages." The major contribution of the first of those civilizations was simply to preserve and transmit the ancient traditions. And the first significant receiver of those goods was the civilization of Islam. A penchant for measurement therein assured Ptolemy a warm reception. His work now became known as the *Almagest*, the greatest composition, because its results were generally quite good and, where new observations pointed up new variations, its powerful methods could be utilized to provide adequate explanations.

6. ALFRAGANUS. *Brevis ac perutilis compilatio Alfragani astronomo*[*rum*] peritissimi totu[m] id contiens quod ad rudiment astronomica est opportunum...

[Ferrarie Andreas Bellfortis, second press, Sept. 3, 1493.]

This work has been included as a sample of Islamic astronomy. Unlike some later efforts of that school, this early study of the elements of astronomy did not either correct Ptolemy or expand upon his system. But, by presenting an intelligible summary of it, Alfraganus contributed to the revival of the science of astronomy in Europe when his work was translated into Latin in the 12th century.

The increasing complexity which resulted from the addition of new circles on circles may have played its part in bringing about an Aristotelean revival–including a preference for the mechanically understandable geocentric spheres–in the Islamic world, especially in Spain in the twelfth century. Almost certainly it was responsible for the expression of dissatisfaction attributed to the Christian King Alfonso X, whose work–especially the so-called *Alphonsine Tables*, which remained in use up to the time of Copernicus–can be considered as a final offshoot of Arabian astronomy in Spain.

7. ALFONSO X. *Tabulae astronomicae* divi Alfonsi, regis Romanorum et Castellae, nuper quàm diligentissimè cum additionibus emendatae...

[Venetijs, ex officinâ literrariâ Petri Liechtenstein, Anno 1518.]

Inasmuch as Ptolemy did write a Planetary Hypothesis *in which he worked out physical models for his geometrical machinery and which was known to the Arabs, although they did not know its author, the late preference for geocentric spheres may have had other than an*

Aristotelean base. Be that as it may, however, these celebrated tables were compiled on Ptolemy's geometrical principles, with Arabic additions. Alphonso's unhappiness with that approach was made known in his statement that "If God had consulted me when creating the world, I should have given Him good advice." Unfortunately, we possess no indications as to what he may have considered a viable alternative.

What is far more important than this alleged statement, however, is that this work may be said to symbolize the emergence of the European segment of the ancient whole from its period of gestation in semidarkness.

The "twelfth century renaissance" accomplished, among other things, the translation of the works of both Aristotle and Ptolemy. Of the two, it was the logic, philosophy, and cosmology of Aristotle that was quickly assimilated rather than the complicated computational astronomy of Ptolemy. The reconciliation of Aristoteleanism and the Christian world-view produced the medieval synthesis of the thirteenth century. In astronomy, on the other hand, that same period witnessed only the publication of a treatise by John of Holywood, better known by his Latinized name Sacrobosco. His *Sphaera Mundi* copied extensively from an elementary Arabic treatise and, in fact, dealt with little but the more obvious results of the daily motion of the celestial sphere; only one of its chapters, as opposed to Ptolemy's nine, treated of the planets.

8. SACROBOSCO. *Sphaero Mundi.* Joannis de Sacro-Busto, Anglici vir clarissimi, Sphaera mundi; et Gerardi Cremonensis Theoria planetarum...

[Venetiis, Franciscum Tenner de Hailbrun, 1478.]

What is really significant about this simplified treatment of Ptolemy, which also quotes from Alfraganus, is that it—or commentaries on it—remained the basic text in astronomical theory for another two centuries. Indeed, as the date of publication demonstrates, the work was still considered important enough to be printed even after the birth of Copernicus, although, as will be seen, the ringing in of changes had begun about two decades before that event.

Aristoteleanism, meanwhile, was subjected to increasingly close scrutiny and important modification. The most significant development of the latter type was the emergence of the theory of impetus as an alternative to Aristotle's theory that motion demanded the continual presence of an external mover. And it was in the framework of this type of work that such thinkers as Nicole Oresme boldly considered, though ultimately–on the basis of Scriptural authority–rejected, the possibility of the earth's rotation. But that speculation and the even bolder, subsequent ones of Nicolas of Cusa were, in keeping with their cosmological settings, unconnected with mathematical astronomical theory.

9. CUSA, Nicholaus de. [*Opera.*] Haec accurata recognitio trium voluminum, operum.

Parisiis, ex. off. Badius Ascensius, 1514.

Probably because his framework was more philosophical–and, specifically, much more mystical–Cusanus went much further than Oresme by removing the earth from the center of an infinite universe as well as endowing it with motion. Moreover, he did not back off from these positions. With Cusanus, therefore, one encounters the beginning of the impact of neo-Platonism and of the road that led to Bruno.

How different it was with Copernicus.

That Copernicus could approach the question of the earth's motion from the opposite point of view was the result of several developments, many of which can be subsumed under the general heading of currents of the Renaissance. Included within that multi-faceted movement were several transitions of fundamental importance: a reorientation from the hereafter to the here and now, from the universal to the individual, from the eternal to the transient, etc. all of which was encouraged, if not caused, by the philosophy of nominalism; a recovery of many lost or ignored works of the classical world, particularly Greek works, including the emergence of a neo-Platonic movement with strong Pythagorean overtones; and, as a result of these and other changes, a growing anti-Aristoteleanism and an insistence upon a judicious hearing for the other voices with which antiquity had spoken. A good deal of this new scholarship was devoted to science, and, within that broad area, to the discipline of astronomy. Significantly, this involved the close study of Ptolemy.

The first individual to engage in that work in any detail was Georg Peurbach, who was born fifty years before Copernicus. Peurbach, who taught at the University of Vienna, began an astronomical textbook based upon the *Almagest*, and also a Latin version specifically of the planetary theory thereof, intended partly as a supplement to Sacrobosco's work. He was hindered in both ventures by the poor quality of the available versions of Ptolemy's work – Latin translations which had been made from Arabic rather than Greek sources and which, in consequence, contained many mistakes and accretions. Peurbach was aided in his efforts, which included observations that revealed gross errors in the *Alfonsine Tables*, by his pupil Johann Müller of Königsberg, known as Regiomontanus from the Latinized form of his birthplace. Because of the untimely death of the former, it was the latter who was destined to study newly available Greek texts of Ptolemy in the original and to complete his teacher's efforts. Although these works did not achieve any advances in planetary theory – except, of course, insofar as they provided an alternative to the prevailing Aristotelean interpretation which had been greatly popularized by its inclusion into such works as Dante's *Divine Comedy* – they did enable a clearer understanding of Ptolemy's treatment of that subject and of its difficulties, problems, and complications.

10. PEURBACH, Georg. *Theoricarum Nouarum* [Planetarum] Textus Georgij Purbachij eu vtili ac praeclarissimâ expositione Domini Francisci Capuani de Manfredoniâ. Item in easdem Reuerendi patris fratris Syluestri de Prierio perfamiliaris Com-

mentatio. Insuper Jacobi Fabri Stapulen. Astronomicon. Omnia nuper summâ diligentia emendata...

[Parisiis, opificis Sumptibus Johannis Parui (Jean Petit) et Reg. Chaude, ron, 1515.]

First published by Regiomontanus in 1472, this work was frequently printed and commented on by various editors in the next hundred years, here, along with Sacrobosco, by F. Capuani de Manfredonia. Despite its title, it was not new. Nor was it entirely the alternative just suggested, since Peurbach proposed a compromise by hollowing out the crystalline spheres till there was room for epicycles inside!

11. REGIOMONTANUS. [Mueller, Johann.] & Peurbach, Georg. *Epytoma Joannis de monte regio In almagestum ptolomei.*

[Venice, Johannes Hamman de Landoia, 31 Aug. 1496.]

Although Regiomontanus has been credited with being a precursor of Copernicus in regard to the rotation of the earth and even, though less frequently, in regard to its revolution around the sun, such claims are erroneous. In this completion of Peurbach's textbook he accepted the Ptolemaic system in every detail.

There can be no question but that Copernicus was greatly influenced not only by these specific outcomes of Renaissance scholarship but by its fundamental predispositions as well.

Although his father died when he was only ten, Copernicus received the education befitting the son of a wealthy merchant through the care of a maternal uncle, who was also responsible for having him early designated a canon of the Cathedral of Frauenburg, a position from which he enjoyed income throughout his life and to which he devoted many of his adult labors. That schooling included the pursuit of the seven liberal arts at the University of Cracow, an old and distinguished institution in which Copernicus was exposed both broadly and astronomically to the old and the new learning. Thus, his training in astronomy involved "the spheres" according to Sacrobosco and planetary theory according to the commentary on Peurbach's

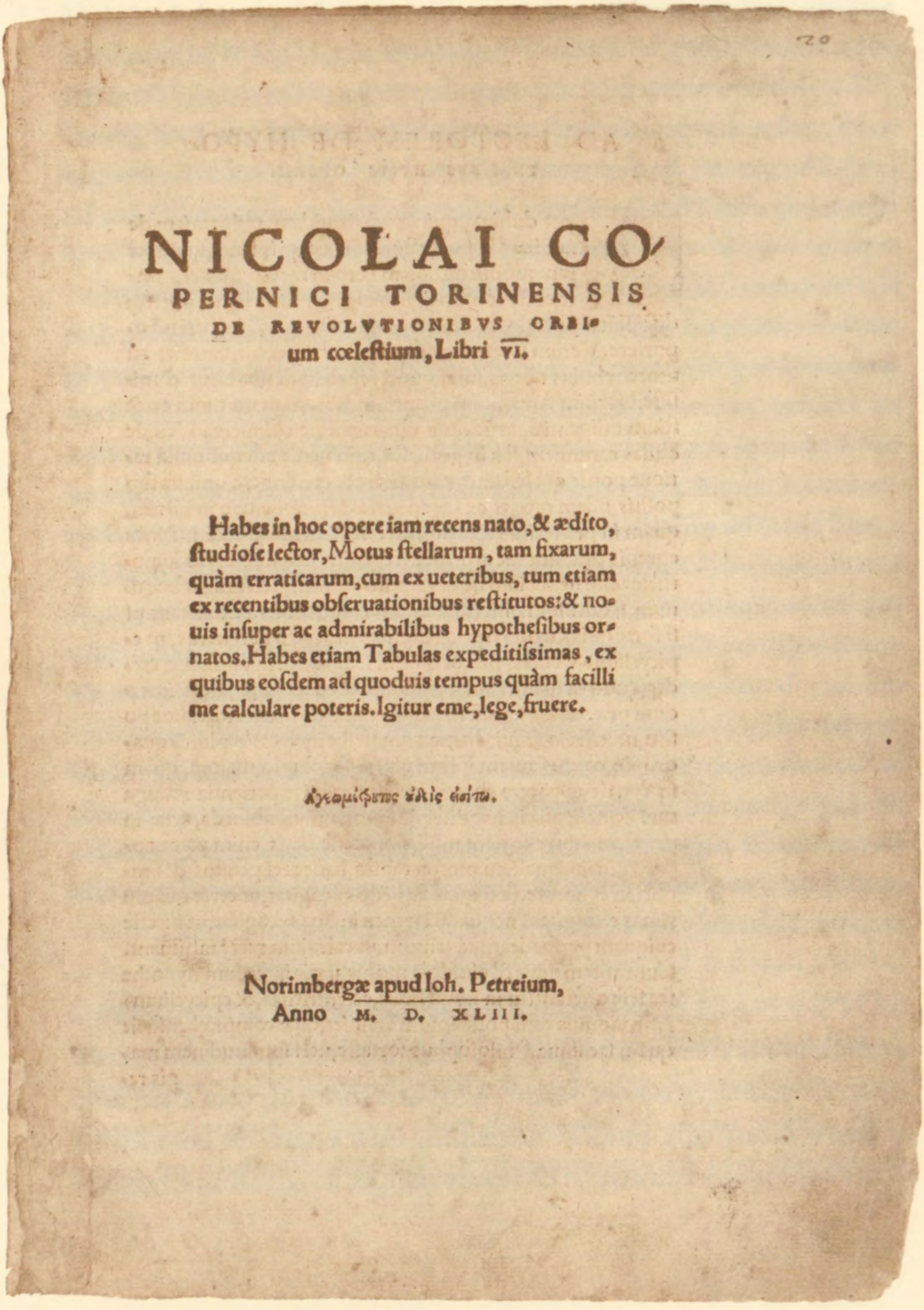
Theoricae written by Adalbert of Brudzewski, a student of Regiomontanus who brought the findings of his master to Cracow along with his own dedication and enthusiasm as a teacher. It is also likely that Copernicus imbibed heavily from the Humanism widespread in the Polish capital, perhaps even knowing and being influenced by Callimachus, from whom, indeed, he may have derived knowledge of and acquaintance with Ficino's *De sole et de lumine* with its neo-Platonic emphasis upon the nobility of the sun.

Certainly if he did not encounter works of this sort in Cracow, he did meet them in Italy, where he went in 1496 to complete his education. Four years of study at Bologna, officially in canon law but including astronomical work under Novara, were followed by a period in Rome during which he probably lectured on astronomy and mathematical calculations in addition to receiving practical experience in the papal chancellery. He thereafter continued various studies, including that of medicine, at the University of Padua before receiving his doctorate at the University of Ferrara in 1503. It was as a true Renaissance man that Copernicus returned to his homeland, where, indeed, he later completed that picture by indulging in drawing and painting, which efforts produced, among other things, a self-portrait.

Although his talents included the making of celestial observations, sometimes with instruments that he had fashioned himself, Copernicus was not primarily an observer nor was his revolution a product of new data. Quite to the contrary, his new interpretation of the organization of the heavens stemmed from his appreciation of the past rather than his attachment to modern observations. Indeed, he caused himself certain difficulties because of his close adherence to the positions–both good and bad–recorded by Ptolemy, whose equant, however, was seen by him as a corruption to be removed if at all possible. Just as he was aware that the equant violated an older axiom, so also was he cognizant of the fact that there had been a considerable diversity of opinion about the heavens. Moreover, it seems clear that he was specifically attracted to Pythagoreanism with its emphasis upon mathematical relationships and its attachment to the sun and the stars as noble bodies, which, by virtue of their superiority, ought to be immobile.

Copernicus saw that by transposing the spheres of the sun and the earth and by endowing the latter with a daily rotation he could gain Pythagorean goals. The sun and the stars would be immobile. The sun could be thought of as ruling over a family of lesser bodies whose movements could now be explained as parts of an interrelated system rather than by a series of separate treatments. As had been the case with Aristarchus, he thus provided an easy solution to the problem of retrogression. But Copernicus had to deal with the post-Aristarchian inequalities as well, and he found it necessary to retain other features of the ancient mathematical theory to that end, an outcome which perhaps in any event might be expected of an individual who considered himself the restorer of an old system rather than the creator of a new one. The universe remained spherical and finite. Planetary movements remained circular and of uniform velocity; indeed, his philosophical restoration of uniform circular motion through his banishment of the equant was thought by Copernicus to be a major advantage of his system. Like Ptolemy, he had to employ occasional eccentrics to achieve this; his system ought actually to be called heliostatic rather than heliocentric. And he also had to utilize epicycles. The number of these was reduced, however, since his single common explanation eliminated an individual epicycle–and, moreover, the largest and most important of the Ptolemaic figures–for each of the five planets. All in all, therefore, Copernicus' revolution, while important, was only a partial one.

12. COPERNICUS, Nicolaus. *De Revolutionibus.* De Revolutionibus Orbium Coelestium, Libri vi. Habes in hoc opere iam recens nato, & aedito, studiose lector, Motus stellarum, tam fixarum, quàm erraticarum, cum et ueteribus, tum etiam ex recentibus obseruationibus restitutos: & nouis insuper ac admirabilibus hy-



NICOLAI CO-
PERNICI TORINENSIS
DE REVOLVTIONIBVS ORBI-
um coelestium, Libri VI.

Habes in hoc opere iam recens nato, & ædito, studiose lector, Motus stellarum, tam fixarum, quàm erraticarum, cum ex ueteribus, tum etiam ex recentibus obseruationibus restitutos: & nouis insuper ac admirabilibus hypothesibus ornatos. Habes etiam Tabulas expeditissimas, ex quibus eosdem ad quoduis tempus quàm facillime calculare poteris. Igitur eme, lege, fruere.

Ἀγεωμέτρητος οὐδεὶς εἰσίτω.

Norimbergæ apud Ioh. Petreium,
Anno M. D. XLIII.

12. Copernicus. *De Revolutionibus*. 1543.

NICOLAI COPERNICI

hendentia. Reliquus igitur A E L, eſt part. II. ſcrup. XII. relinqtur qui ſub L E D part. CXV. ſcrup. LIII. Similiter in acronychio ſecundo oſtendetur, quòd cum in triangulo B D E duo latera data B D, D E, compræhendant angulum B D E, part. CXIII. ſcrup. XXXV. angulus D B E per demonſtrata triangulorũ planorũ fuerit pt. VII. ſcrup. XI. & reliquus D E B pt. LIX. ſcru. XIII. baſis quoque B E, partiũ 30668, quarum D E eſt 30000, et B M, 500. Totus quoq; E B M pt. LXXIIII. ſcrup. XXXVI. Sic q̃queın triangulo E B M datorũ laterũ datũ angulum cõpræhendentiũ, demonſtrabitur qui ſub B E M, angulus part. II. ſcru. XXXVI, à q̃ relinquitur D E M part. LVI. ſcru. XXXVIII. Deinde qui ſupeſt exterior à perigæo M E G part. eſt CXXIII. ſcru. XXII. ſed iam demonſtratũ eſt, ꝙ angulus L E D, fuerit part. CXV. ſcru. LIII, qui ſequitur ipſum, exterior, q ſub L E G, partiũ erit LXIIII ſcrup. VII. quiq; cũ G E M iam inuẽto colligit part. CLXXXVII. ſcrup. XXIX, quarum CCCLX, ſunt quatuor recti, quæ congruunt diſtantiæ apparẽti à primo acronychio ad ſecundũ. Eſt etiã pari modo uidere in acronychio tertio. Demõſtratur eñ D C E angulus part. II. ſcrup. VI. & E C latus partiũ 33407. quarum eſt C D 30000. Toto igitur angulo E C M exiſtente part. XVIII. ſcru. XLII. datiſq; iam C E, C N, lateribus trianguli E C N, conſtabit angulus

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angulus C E N, ſcrup. L. qui cum D C E componit partes II. ſcrup. LVI. quibus angulus apparentiæ D E N, minor eſt æqualitati, ſub F D C. Datur ergo D E N part. XIII. ſcrup. XL, quæ etiam ferè cõgruunt apparẽtiæ inter ſecundũ & tertium acronychium obſeruatæ. Quoniam igitur apparuit Martis ſtella in hoc loco, uti narrauimus, à capite Arietis ſtellati in part. CXXXIII. ſcrup. XX. & angulus F E N, oſtenſus eſt part. XIII. ſcrup. XL. ferè. Manifeſtum eſt retrorſum numerãti, quòd apogæi locus eccentri in hac ultima conſideratione fuerit in part. CXIX. ſcrup. XL, adhærentium ſtellarum ſphæræ. Quem tempore Antonini Ptolemæus in part. CVIII. ſcrup. L, inueniebat, quiq; propterea ad nos uſq; in decem grad. & dextante unius eſt permutatus in conſequentia. Centrorum quoq; diſtantiam minorem inuenimus in part. 40, quibus quæ ex centro eccẽtri datur 30000. non quòd errauerit Ptolemæus uel nos, ſed argumento manifeſto, quòd centrum orbis magni telluris acceſſerit centro orbis Martis, Sole interim immobili permanente. Reſpondẽt enim hæc ſibi inuicem ferè, ut infra luce clarius apparebit. Exponatur iam orbis ipſe terræ annuus ſuper E centro, cum dimetiente ſuo, qui ſit S E R, ad C D propter æqualitatem reuolutionum, ſitq; in R apogæum æquale ad ſtellam, in S perigæum, in T terra. Secabit autem E T extenſa, in qua uiſus ſtellæ C D in X. Erat aũt in ipſa & X uiſus ad partes lõgitudinis, ut dictũ eſt hoc ultimo loco, part. CXXXIII. ſcrup. XX. Angulus quoq; D X E, demõſtratus eſt part. II. ſcru. LVI. Eſt eñ differẽtia qua X D F angulus ipſi X E D maior exiſtit medius apparenti. Sed ipſe S E T, æqualis eſt ei q ſub D X E, alterno, eſtq; pſthaphæreſis cõmutatiõis, quæ cũ ablata fuerit à ſemicirculo, relinqt part. CLXXVII. ſcru. IIII. anomaliã cõmutatiõis æqualẽ ab R apogæo ipſius æq̃litatis deducta. Vt etiã hic demõſtratũ habeamus, ꝙ anno Chriſti M. D. XXIII. octauo Calẽd. Martij, ſeptẽ horis æqnoctialibus ante meridiẽ, Martis ſtella fuerit ſuo medio motu lõgitudinis in part. CXXXVI. ſcru. XVI. Et anomalia cõmutationis eius æqualis in part. CLXXVII. ſcrupul. IIII, atq; ſumma abſis eccentri in part. CXIX. ſcru. XL. quæ erant demonſtranda. R ij

12. Copernicus. *De Revolutionibus*. 1543.

pothesibus ornators. Habes etiam Tabulae expeditissimas, ex quibus eosdem ad quoduis tempus quàm facilime calculare poteris...

Norimbergae, apud Joh. Petreium, 1543. (No Errata.)

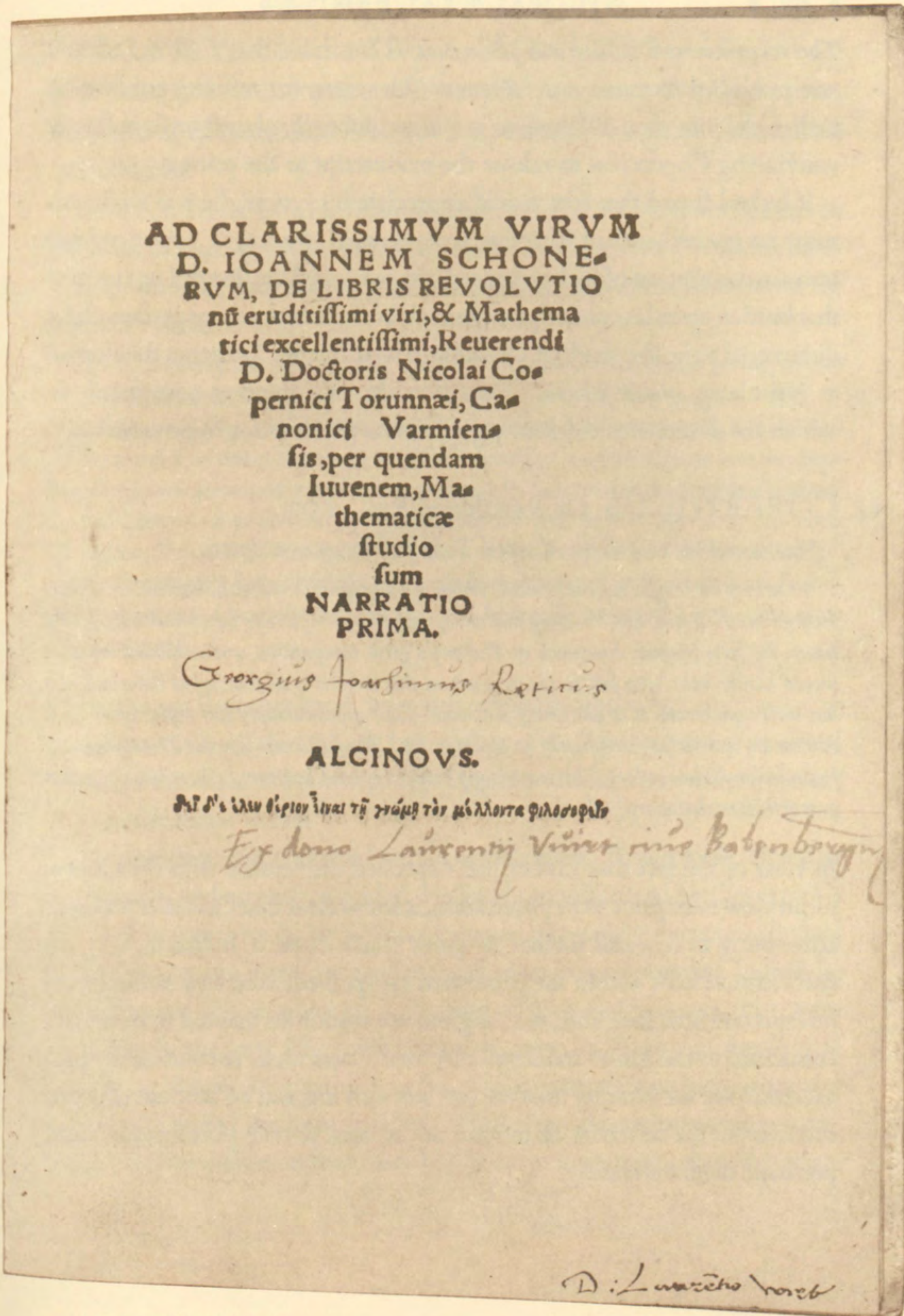
As might be expected in light of what has just been said, Copernicus' book, after setting forth arguments in favor of the earth's mobility, was a kind of re-shuffled version of the Almagest *when it turned to the technical mathematics involved. Not only did it duplicate much of Ptolemy's machinery, but his method and structure as well; format, language, and arrangement of subject matter remain much the same. That said, however, one must then acknowledge the changes made–and the resultant simplification introduced–by virtue of the movement of the earth and the removal of the equant. To attempt to demonstrate these contributions, this copy of the* De revolutionibus *has here been opened to the Copernican equivalent of the Ptolemaic diagram dealing with the eccentricity of Mars. Copernicus is nothing if not clearer!*

Although he had apparently accepted his new paradigm in the early years of the sixteenth century, Copernicus published his epochal *On the revolutions of the heavenly spheres* only in 1543. A good deal was known about it before that time. Copernicus himself wrote an earlier brief sketch of his system, and even though this *Commentariolus* was not printed during his lifetime, a number of handwritten copies circulated for a time. It was perhaps in this way that a young professor of mathematics at the University of Wittenburg, George Joachim, known as Rheticus, heard of Copernicus' ideas and, in 1539, went to study with him. Quickly persuaded of the validity and value of the Copernican system, Rheticus wrote a survey of its principal features which was published in 1540.

13. [COPERNICUS.] Rheticus, Georg Joachim. Ad Clarissimum Virum D. Ioannem Schonerum. De Libris Revolutionum...Doctoris Nicolai Copernici...NARRATIO PRIMA.

Gedani, 1540. (Osiander Letter on verso of the title-page.)

Rheticus addressed this lengthy review of the Copernican system to his teacher Johann Schoner and had it printed at Danzig without his own name attached. Subsequent editions, including its reproduction in all of the Latin editions of Copernicus' work, rectified that situation.



AD CLARISSIMVM VIRVM
D. IOANNEM SCHONE-
RVM, DE LIBRIS REVOLVTIO
nũ eruditissimi viri, & Mathema
tici excellentissimi, Reuerendi
D. Doctoris Nicolai Co-
pernici Torunnæi, Ca-
nonici Varmien-
sis, per quendam
Iuuenem, Ma-
thematicæ
studio
sum
NARRATIO
PRIMA.

Georgius Joachimus Rheticus

ALCINOVS.

δεῖ δ' ἐλευθέριον εἶναι τῇ γνώμῃ τὸν μέλλοντα φιλοσοφεῖν

Ex dono Laurentij Vuirt ...

D: Laurentio ...

13. Rheticus. *Narratio Prima.* 1540.

The response to this *Narratio prima* was so favorable that a second edition was published the next year. Whatever his reason for refusing publication earlier, the reception of Rheticus' work undoubtedly played a role in finally convincing Copernicus to release the manuscript to the printer.

If he had feared that few would appreciate his system, he was right. Almost no one, other than Rheticus, was prepared to accept Copernicus' system as a description of reality. Indeed, the published version did not impose that burden upon his contemporaries for it bore an anonymous preface – later discovered to be the work of Osiander, a well-known Lutheran theologian at Nürnberg, under whose supervision the printing was completed – in which the doctrine of the moving earth was presented as hypothesis only.

14. COPERNICUS. *De Revolutionibus*... 1543.

(Same as No. 12.) With: Cancel Title and Errata on verso.

Thanks to the long delay, the printed version of the great book was delivered to Copernicus only on his deathbed, thus allowing him no opportunity to reject – as he undoubtedly would have – the false preface. Inasmuch as Ptolemy's great composition was exhibited twice, it would hardly have been fair to the man whom this exhibit is celebrating to have had him less well represented. It is extremely fortunate – since approximately 200 copies of the first edition are known (approximately 40 copies in the United States) – that the Honeyman collection allows this to be done. This second copy has been opened, however, to the non-Copernican part of this revolutionary book.

In view of the fact that Luther had expressed displeasure with the Copernican view even prior to its publication, it seems clear that Osiander was here attempting to forestall further religious attack upon it. In this he was unsuccessful, at least within the Protestant camp. Dedicated to a rather literal interpretation of the Bible, the religious revolutionists insisted that Joshua's command to the sun to stand still obviated Copernicus' revolutionary premise that the earth rather than the sun was moving, and no amount of argument about the relativity of motion or the need to save phenomena could persuade them differently.

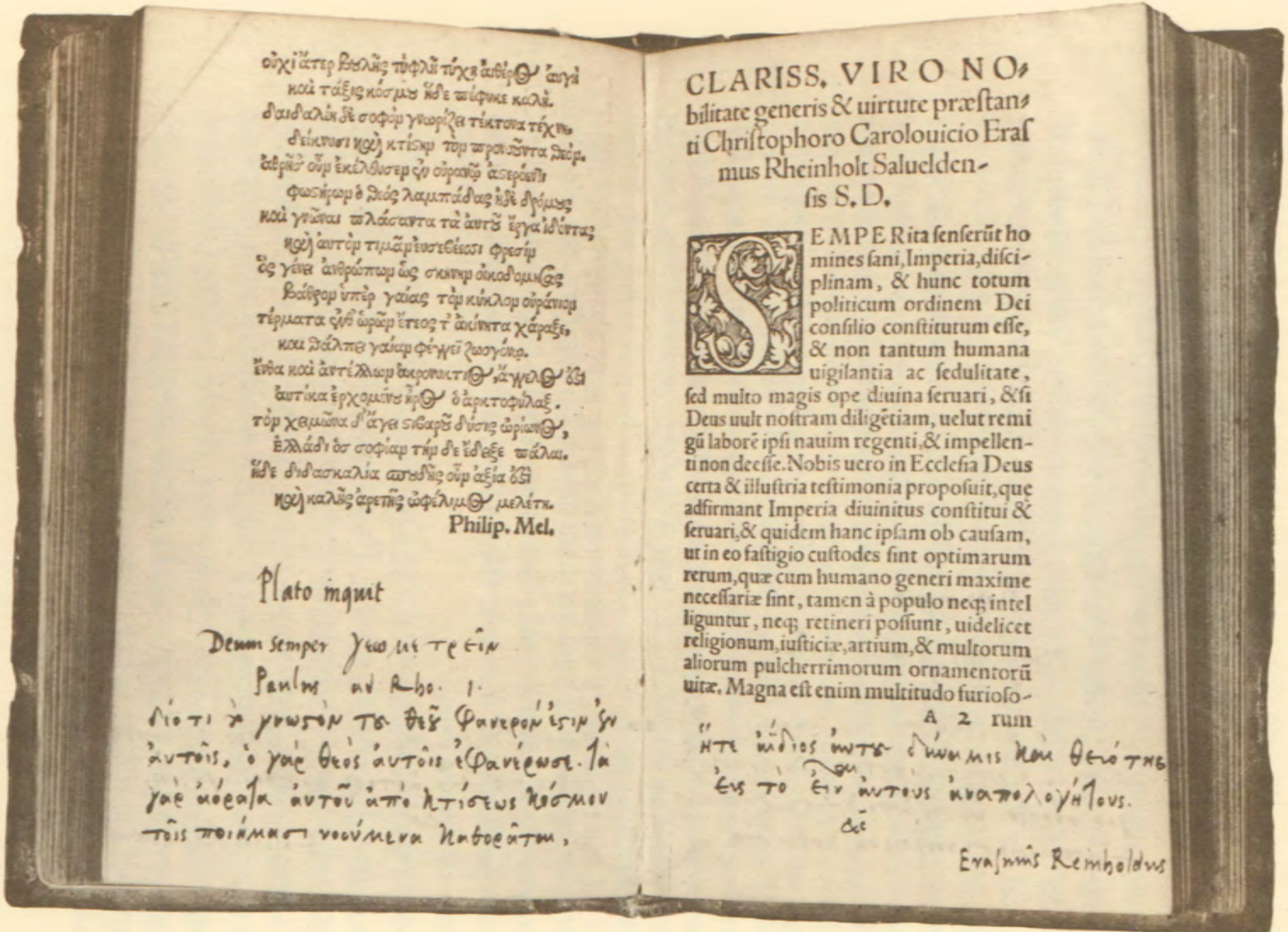
15. PTOLEMY, Claudius. Reinhold–Melanchthon. Ptolemaei Mathematicae constructionis Liber primus graece & latine editus. Additae Explicationes Aliquot locorum ab Erasmo Rheinholt Salueldensi.

Wittebergae, Ex Officina Iohannis Lufft, 1549. With Ms. notes in Latin in the hand of, and signed by Erasmus Reinhold; and with a Ms. Greek notation on the title, with the name of Philippus Melanchthon, who wrote the prefatory verses.

The exhibition of this book introduces into this collection a third, though partial, copy of Ptolemy's Almagest. *It has been included because it bears a prefatory poem, in Greek, by his colleague at Luther's university, namely the theologian Melanchthon, who had written a preface to a new edition of Sacrobosco in 1531, the same year in which he formulated the Augsburg Confession. Because he was, thus, the spokesman for Lutheranism, Melanchthon's attitude toward Copernicanism provides an "official Protestant line" on that doctrine. In his* Initia Doctrinae Physicae *(Wittebergae, 1551), Melanchthon invoked other "divine testimonies" besides the passage in Joshua against Copernicus, including texts from Ecclesiastes and Psalms. Interestingly, it had been primarily the latter that had earlier persuaded Oresme against the earth's motion.*

Catholics, on the other hand, were not originally upset. Not only was Copernicus a canon of the Church, but various of its dignitaries were involved in the publication of his work. The Catholic attitude was to be different toward Giordano Bruno.

A renegade monk endowed with a restless spirit, Bruno took steps that Copernicus had carefully avoided. He had been influenced by Copernicus, but his ideas were probably primarily shaped by a sixteenth century revival of Greek atomism. Bruno argued in favor of an infinite universe. Indeed, he went beyond this to advocate a plurality of worlds. His views, thus, were surprisingly modern. They also, however, raised a variety of theological questions: Where, for example, in his infinite universe were purgatory and paradise? Or, did the human beings of other worlds require redemption, and, if so, did this mean that there had been an infinite number of appear-


Philip. Mel.

Plato inquit

Deum semper γεωμετρεῖν

Paulus ad Rho. 1.

διότι τὸ γνωστὸν τοῦ θεοῦ φανερόν ἐστιν ἐν αὐτοῖς, ὁ γὰρ θεὸς αὐτοῖς ἐφανέρωσε. τὰ γὰρ ἀόρατα αὐτοῦ ἀπὸ κτίσεως κόσμου τοῖς ποιήμασι νοούμενα καθορᾶται,

CLARISS. VIRO NObilitate generis & uirtute præstanti Christophoro Carolouicio Erasmus Rheinholt Salueldensis S. D.

SEMPER ita senserũt homines sani, Imperia, disciplinam, & hunc totum politicum ordinem Dei consilio constitutum esse, & non tantum humana uigilantia ac sedulitate, sed multo magis ope diuina seruari, & si Deus uult nostram diligẽtiam, uelut remigũ laborẽ ipsi nauim regenti, & impellenti non deesse. Nobis uero in Ecclesia Deus certa & illustria testimonia proposuit, quę adfirmant Imperia diuinitus constitui & seruari, & quidem hanc ipsam ob causam, ut in eo fastigio custodes sint optimarum rerum, quæ cum humano generi maxime necessariæ sint, tamen à populo neq; intelliguntur, neq; retineri possunt, uidelicet religionum, iusticiæ, artium, & multorum aliorum pulcherrimorum ornamentorũ uitæ. Magna est enim multitudo furioso-

A 2 rum

ἥτε ἀΐδιος αὐτοῦ δύναμις καὶ θειότης, εἰς τὸ εἶναι αὐτοὺς ἀναπολογήτους.

Erasmus Reinholdus

15. Ptolemy [Reinhold]. *Mathematicae constructionis*. 1549.

ances of Christ? Small wonder that the Inquisition was disturbed or that Bruno, after several years of imprisonment at its hands, was burned at the stake in 1600.

16. BRUNO, Giordano. *De Monade.* Numero et Figura liber Consequens Quinque de Minimo magno et Mensura. Item de Innumerabilibus, immenso, et Infigurabili; seu de Universo & Mundis libri octo.

Francofurti, apud Joan. Vvechelum & Petrum Fischerum, 1591.

As suggested earlier, Bruno's speculations were a kind of continuation and elaboration of those of Cusanus, and, thus, could have been put forward without the intermediacy of Copernicus' work. But the latter had intervened and, more importantly, had been utilized by Bruno, who, incidentally, had earlier been in trouble in Calvin's Geneva. Still, it was his immense outstripping of Copernicus and his greater radical mysticism than Cusanus that brought him to a fiery end.

Bruno's speculations represented one kind of completion of the Copernican revolution. But, while his ideas represent a sort of breakthrough, they were philosophically rather than scientifically based. The period between Copernicus and Bruno saw steps taken toward providing a basis for a scientific completion of the new paradigm.

Osiander's preface had also implied that the Copernican "hypotheses" deserved consideration because of their greater simplicity. Here he was more successful, for the new system soon became the basis for the calculation of tables, whether those involved accepted it as reality or not. The first important instance of such use was that by Erasmus Reinhold, professor of astronomy at Wittenberg, whose "Prussian Tables" came rapidly to replace the grossly out-of-date compilations of Alfonso. Indeed, this effort was employed in the Gregorian reform of the calendar, a goal that Copernicus had hoped his restored astronomy would help achieve. Reinhold, however, was not a declared Copernican.

17. REINHOLD, Erasmus. *Prutenicae Tabulae Coelestium Motuum.* Tübingen, U. Morhard, 1551.

Although Reinhold referred to Copernicus in a most complimentary manner in an edition of Peurbach's Theoricae *that he brought out in 1542, only two years after his Wittenberg colleague Rheticus had published his* Narratio prima, *he did not commit himself to the new system either then or later. Indeed, as suggested above (item 15), he subsequently prepared a new partial edition of the* Almagest. *The tables displayed here did not necessitate a confession of scientific faith. But their demonstration of the excellence of Copernicus' mathematics helped immeasurably to bring his system into general recognition and eventual acceptance.*

One example of the quick adoption of these new Prussian tables was the appearance of the *Ephemeris for the Year 1557 according to the Principles of Copernicus and Reinhold for the Meridian of London*, authored by the otherwise unknown John Field. The preface to this work, by the rather well known mathematician John Dee, took the Osiander-Reinhold position: without discussing its merits or reality, Copernicanism was an eminently useful computational system. Pontus de Tyard subsequently did the same in his *Ephemeris of the Eight Spheres*, even though he was probably an actual Copernican.

One obstacle to a broader acceptance of the system as actuality was simply that, except for the early work of Rheticus, there were almost no elementary presentations of it. The University of Salamanca did revise its statutes in 1561 so as to permit the course in mathematics to consist of Euclid, Ptolemy, or Copernicus at the choice of the students, but there is no evidence that that last option was exercised. And even prior to this in England, Robert Recorde, although briefly describing the Copernican system in his *Castle of Knowledge*, clearly considered it too difficult to attempt to adduce arguments in its favor in an introductory textbook.

18. RECORDE, Robert. *The Castle of Knowledge...* [Colophon: Imprinted at London by Reginalde Wolfe, 1556.]

This pioneer English-language treatise on astronomy is in the form of a dialogue between master and pupil. Among the topics discussed is the confrontation of the Copernican system *with the traditional views of the universe. Interestingly, the pupil represents the latter position and is chastised by the master for condemning something that he does not understand. Although Recorde has his spokesman promise at another time to declare Copernicus' supposition in such a way that the student will have to credit it, he did not subsequently find the occasion to do so.*

This raises the point that there was a far more important obstacle to a broader acceptance of the new astronomy, namely, that there were, in fact, quite valid scientific reasons, both specific and general, for opposing it. Leaving aside various problems associated with the rotation of the earth which had been raised and answered by Oresme, the major specific argument was that the earth's annual revolution around the sun should cause an apparent shift in the position of the fixed stars and that this "parallax" could not be observed. To move the stars to such great distances that parallax would be unobservable–as Aristarchus and Copernicus did–was to place a greater strain upon the imagination than that required by the Ptolemaic system's need to move the sphere of the stars at a very great speed. The latter, after all, was acceptable within the framework of Aristotelean physics. This brings up the general scientific argument against Copernicus, namely, that he provided no alternative to the broad Aristotelean paradigm. Just as his mathematical treatment simply reshuffled Ptolemy, so his introduction of a moving earth simply rejected one of several cosmological principles; the post-Aristotelean breach continued until a new physics supported the new astronomy.

Interestingly, however, one outcome of this was to make the Copernican theory, and public commitment to it, appeal to the radical thinkers of the sixteenth century. Many discussions of Copernicanism came to be set within the framework of anti-Aristoteleanism, and this probably explains why many favorable references to Copernicus were made by men who, like Bruno, were not astronomers or even scientists at all, as well as why it was often associated, again as with Bruno, with free thought or extreme atomism. Such was not always the case. The most obvious instance of the rejection of the authority and domination of Aristotle was Pierre de la Ramée's defense of the thesis that "all the things Aristotle said are wrong." Yet Ramus, as he is better known, while expressing admiration for Copernicus, rejected his system along with all others that proposed to explain the heavens by hypotheses rather than by simple observation and arithmetical "countings-up" of celestial motions.

19. RAMUS, Petrus [Pierre de la Ramée.] *Scholarum mathematicarum libri unus et triginta.*

Basileae, per Eusebium Episcopium, & Nicolai fratris haeredes, 1569.

Although Ramus was not a scientist per se, he contributed significantly to the scientific revolution by espousing his anti-Aristoteleanism and effusing a general scientific "spirit" from his chair in philosophy at the Collège Royal in Paris, to which institution, moreover, he willed money for the endowment of an additional chair of mathematics. The work on display is the major one in which he advocated an "arithmetical" astronomy.

One individual who heard Ramus' message was the young Danish astronomer, Tycho Brahe, with whom precise observation became a cornerstone for astronomical advance.

20. BRAHE, Tycho. *Astronomiae Instauratae Mechanica.*

Wandesbvrgi, 1598. [Colophon: Impressum Wandesbvrgi in Arce Ranzoviana prope Hamburgum sita, propria Authoris Typographia opera Philippi de Ohr Chalcographi Hamburgensis, 1598.]

Tycho's observational career was made possible by the largesse of the King of Denmark who granted him the island of Hveen, with money to build an observatory and the promise of an annual income from the state for his support. There, at Uraniborg, he made significant observations for more than 20 years, including, of even greater importance than his catalogue of stars, recordings of the position of the planets throughout their courses rather than just, as had been the traditional practice, at such points as the beginning and end of retrograde motion. This work offers detailed descriptions of one of the keys to his success, to wit, his observatory and its instrumentation. Important as they undoubtedly were, those things should not be allowed to obscure the other key, the simple fact that he was blessed with extraordinary eyesight.

Among his many observations, those of a new star in 1572 and of a comet beyond the moon in 1577 were of particular importance to the ultimate success of the new astronomy, not because they added to Copernicanism but because, instead, they were damaging to Aristotelean physics; both raised fundamental doubts about the cosmological principle of the unchangeability of the sublime heavens.

21. BRAHE, Tycho. *De nova et nullius aevi memoria prius visa Stella...*
Hafniae, Impressit Lavrentivs Benedictij, 1573.

This was but one of many accounts of the nova of 1572. Indeed, Tycho was inspired to write it, at least in part, because so much rubbish had appeared on this startling phenomenon. Although he did raise herein the basic question of the alleged immutability of the heavens, probably an even more important outcome of his observation was the fact that it served to recall him to astronomy from his then concern with chemistry and medicine.

22. BRAHE, Tycho. *Astronomiae Instauratae Progymnasmata*, Quorum haec Prima Pars De Restititione Motuum Solis Et Lunae Stellarumque Inerrantium Tractat. Et. Praetereá de admiranda Nova Stella Anno 1572 exorta luculenter agit.
Typis Inchoata Uraniburgi Daniae. Absoluta Pragae Bohemiae, 1602.

Because the previous small and extremely rare work was not distributed at all widely, Tycho later returned to the subject of the new star in this treatise, which, however, came also to embrace other aspects of astronomy. Indeed, because it became a place where he could continue to enter important results of his observations, such as corrections in the values of astronomical constants handed down from antiquity, he never finally completed the work, which, thus, was not published until a year after his death.

Tycho also seemed to be acting upon the other part of Ramus' advice when he suggested that the comet which passed through the popularly continuing crystalline spheres might have an oblong orbit. But this was the limit of his flexibility; he could not otherwise abandon circular motion. Like Copernicus, Brahe could not accept the Ptolemaic system. But, unlike Copernicus, he could not believe in the motion of the earth, both because of Scriptural strictures and because of the parallax problem. So, he invented a system of his own, half-way between Ptolemy and Copernicus–and really only a large step beyond that of Heraclides–in which the sun revolved around the earth but the other planets revolved around the sun.

23. BRAHE, Tycho. *De mundi aetherei recentioribus phaenomensis liber secundus.*

[Praga Bohemorum...typis Schumanianis, 1603.]

This is the work in which Tycho deals with the comet of 1577. It is also in this work that he sets forth the system that he had found, "as if by inspiration," four years before the book was written, i.e., in 1583. Although ready from the press at Uraniborg in 1588, the work was not regularly published until 1603. Some copies of it had been distributed, however, so that the possibility existed that plagiarism could take place.

Because it was the *mathematical* equivalent of Copernicanism, this Tychonic system–which found its way into print first from the possibly plagiaristic pen of one Nicolai Reymers–presented itself as a viable alternative to those who rejected the earth's motion, or, at least, its revolution around the sun.

24. BRAHE, Tycho. *Epistolarum astronomicarvm libri.*

S. Imprembantur Vraniburgi. Daniae, prostant Francofurti apud Godefridum Tampachium, 1610.

Many of Tycho's objections to the Copernican system–both religious and astronomical–were stated in an exchange of correspondence with Christopher Rothmann, a Copercian supporter. Because of the delay in the publication of the previous work, these objections became known through the printing of that letter exchange before his own system had appeared from his pen. In these letters he also attacks Reymers' alleged plagiarism of that system, although it should be noted both that this compromise solution could easily have occurred independently–or with the help of Heraclides–to others, and that there is no proof to substantiate Tycho's claim. Because the Honeyman collection's copy of the first edition of this work is bound with the previous treatise, it was deemed appropriate to exhibit here that collection's copy of the second edition, which is identical to the first but bears a new title.

It was a compromise that won many adherents among the technically proficient non-Copernican astronomers of the day, beginning with Tycho's Danish disciple, Longomontanus.

25. LONGOMONTANUS, K. Sorensen. Christ. Severini Longomontani, *Astronomia Danica*, in duas partes distributa...ad observationes Tychonis Brahae et proprias, complectitur, cum appendice de stellis novis et cometis.

Amstelodami, 1622. (Not present.)

Prior to the appearance of Kepler in Tycho's circle, Longomontanus was Brahe's chief assistant and left Denmark in his company. Because he later returned to a chair in mathematics and a new observatory in Copenhagen and because this treatise was mainly founded on Tycho's work, Longomontanus' designation of it as the Danish astronomy seems doubly appropriate. He did not adopt the Tychonic system in toto, *however, for he admitted the rotation of the earth.*

That it enjoyed considerable vitality is seen in the fact that, although modified in several significant particulars, it formed the basis of the Jesuit Riccioli's *Almagestum Novum*, the high-water mark of technical opposition to Copernicanism after the condemnation of that doctrine by the Inquisition's Index of Prohibited Books in 1616.

26. RICCIOLI, Giovanni Battista. *Almagestum Novum,* Astronomiam veterem novamque complectens, Observationibus aliorum, et propriis novisque Theorematibus, Problematibus, ac Tabulis promotam, in tres Tomos distributam, Tomos i [all published]...

Bononiae, Haer. Vict. Benati, 1651.

Although it acknowledged its debt to Tycho, this new Almagest was really closer to Heraclides since Riccioli adopted sun-centered revolution only for Mercury, Venus, and Mars. Riccioli fully discussed and rejected the new astronomy, claiming that he had stated "40 new arguments in behalf of Copernicus and 77 against him."

Still, the most advanced thinkers viewed the struggle as one between Ptolemy and Copernicus. This was true, for example, of Thomas Digges, who not only defended the latter to his English contemporaries of the 1570's but made the most important parts of Book I of *De revolutionibus* available to them in a translation which went through at least seven editions between 1576 and 1605.

27. DIGGES, Thomas. *Alae seu Scalae Mathematicae,* quibus visibilium remotissima Coelorum Theatra Conscendi...

Londini [Thomas Marsh], 1573.

Although it used to be commonly said that it was Bruno who introduced Copernicanism into England during his visit there in 1583-85, we now know that it was this student of John Dee who must receive the credit for this by virtue of the major defense of that doctrine that he offered in the book on display.

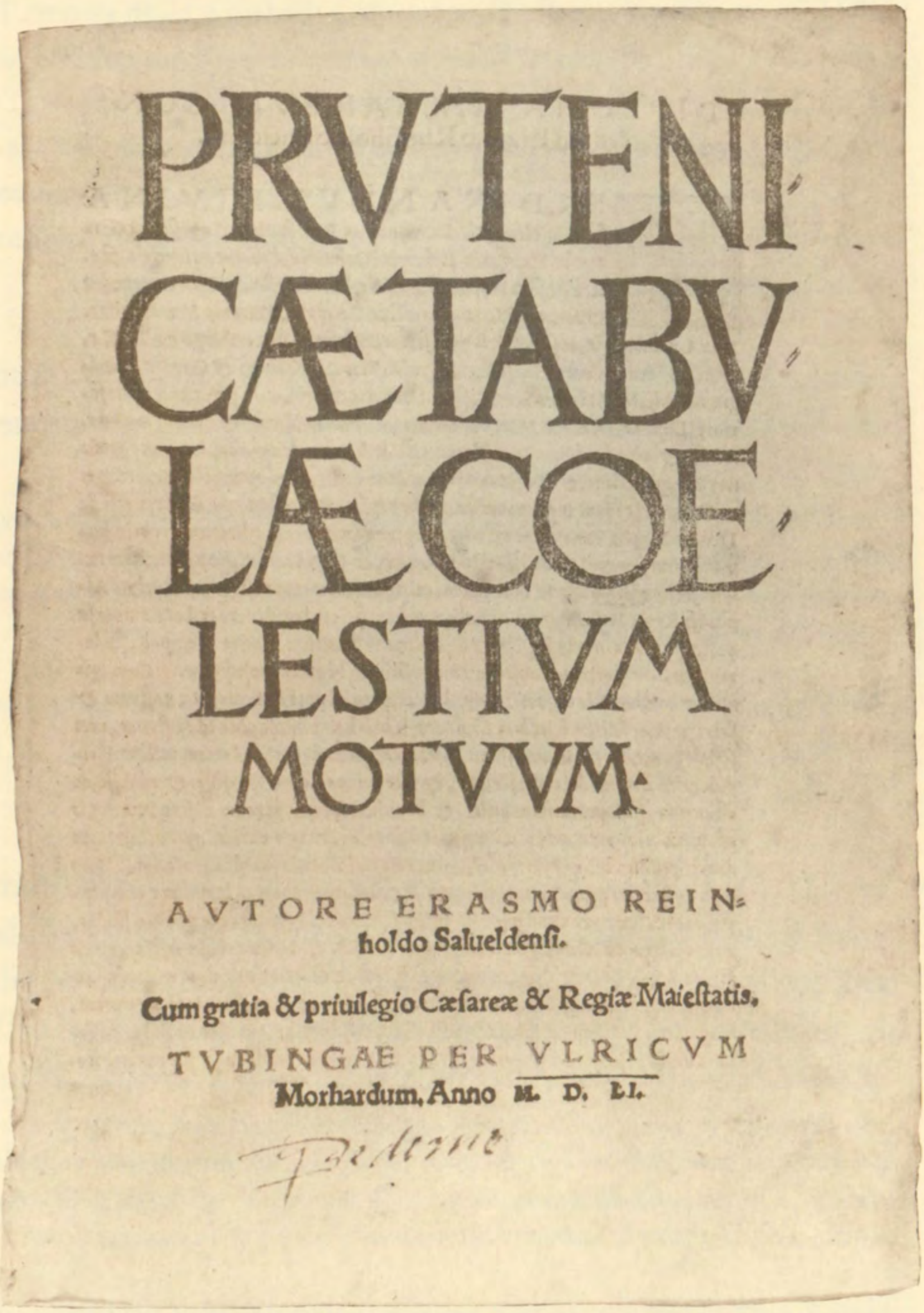
28. DIGGES, Leonard & Thomas. *A Perfit Description of the Celestiall Orbes,* by Thomas Digges, included in: *Prognostication everlasting of righte good effecte,* fruictfully augmented by the auctour... chosen rules to judge the Weather by the Sunne, Moone, Starres, Comets, Rainebow, Thunder, Cloudes...

Published by Leonard Digges, Gentleman. Lately corrected and augmented by Thomas Digges his Sonne. Imprinted at London by Thomas Marsh, 1578.

The partial Ptolemy is here offset by a partial Copernicus, although this translation, probably from one of the two copies of the De revolutionibus *known to have been owned by John Dee, is really more of a paraphrase. It is here published in the third edition of a work by his father, Leonard Digges, rather famous for his treatises on mensuration and surveying.*

More importantly, it was true of Galileo and Kepler.

It was Galileo who first turned a telescope on the heavens in 1609. The discoveries that he made in this fashion—most significantly, spots on the sun, mountains on the moon, the first four satellites of Jupiter, and the phases



PRVTENI-
CÆ TABV-
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LESTIVM
MOTVVM.

AVTORE ERASMO REIN-
holdo Salueldensi.

Cum gratia & priuilegio Cæsareæ & Regiæ Maiestatis.

TVBINGAE PER VLRICVM
Morhardum, Anno M. D. LI.

17. Reinhold. *Prutenicae Tabulae.* 1551.

of Venus–are often credited with supporting the Copernican system. This is true only to a limited extent. Telescopic observations of sunspots and lunar mountains had the same significance as the naked eye observations of the nova of 1572 and the comet of 1577. The Jovian satellite observations did partially justify Copernicanism by demonstrating that centers of motion other than the earth did exist and by providing an argument of parallelism in that the Jovian system could be seen as a miniature solar system.

29. GALILEI, Galileo. *Sidereus Nuncius* magna, longeqve admirabilia Spectacula pandens, suspiciendaque propoens vnicuique... Venetiis, Apud Thomam Balionum, 1610.

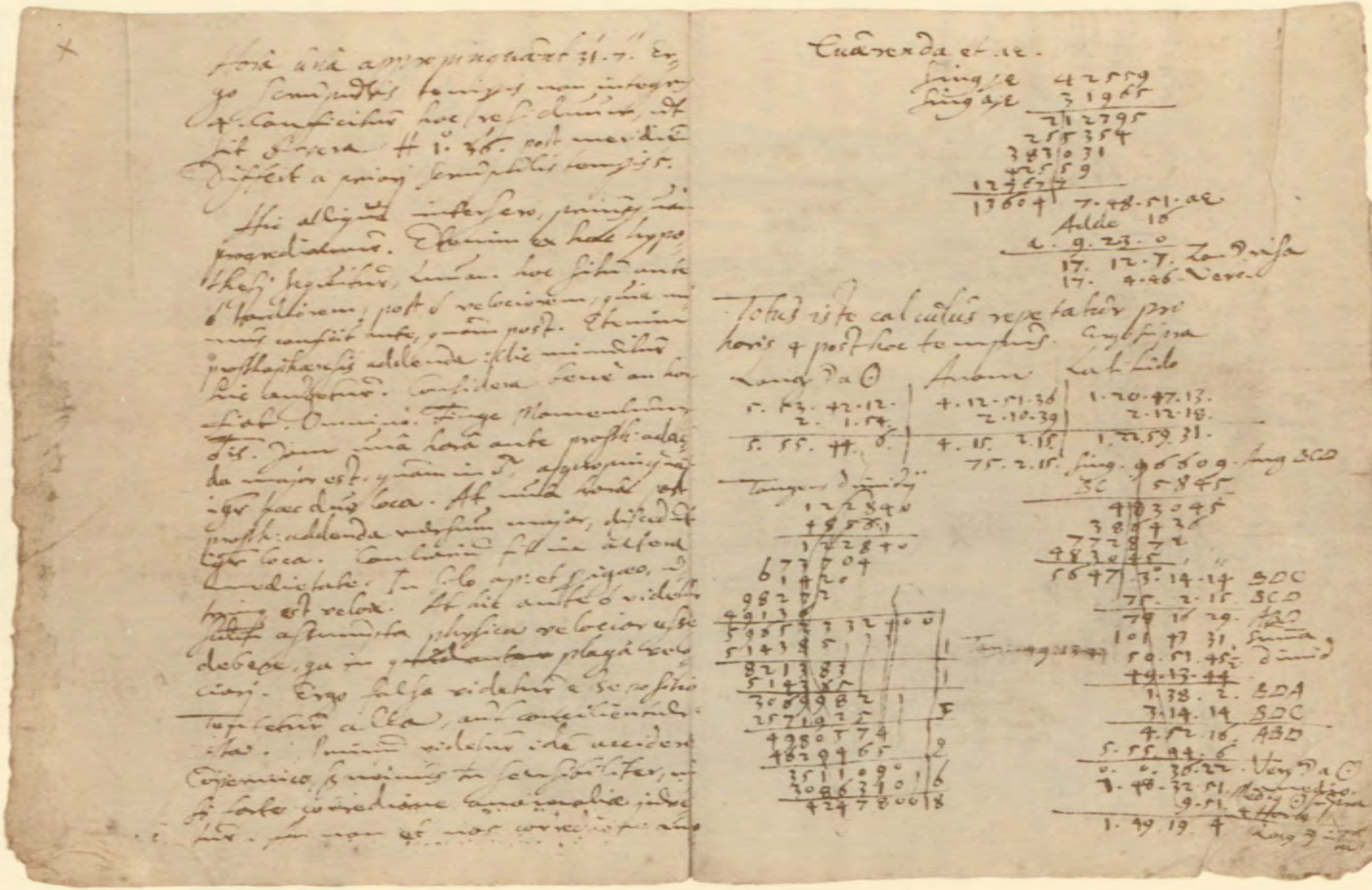
It is in this Starry Messenger *that Galileo described his telescopic discoveries of mountains on the moon and the satellites of Jupiter and used the latter to answer those critics of Copernicanism who had argued that a moving earth would leave the moon behind. Further, he promised to prove the earth to be itself a wandering body in a later "System of the World."*

The Venus observations were actually the most scientifically important, however, for they revealed that Venus did undergo a gibbous phase, an impossibility in the Ptolemaic system.

30. GALILEI, Galileo. *Istoria E Dimostrazioni Intorno Alle Macchie Solari* E Loro Accidenti, compresse in tre Lettere scritte all'illustrissimo Signor Marco Velseri [e pubblicata da Angelo de Filis,] si aggiungono nel Fine le Lettere, e Disquisizioni del finto Apelle... Roma Giacomo Mascardi, 1613. (With the famous portrait by Villamoena.)

In this "letter on sunspots," Galileo not only advanced his claim to priority for this discovery over the Jesuit Scheiner but rejected the latter's idea that the spots were small planets revolving about the sun. Galileo placed this phenomenon, instead, right on the sun's surface. It was also in this work that he announced his important discovery of the phases of Venus.

Thus, while not proving the new paradigm, they did make the maintenance of the old one untenable.



33. Kepler. Holograph.

38. Kepler. *Tabulae Rudolphinae*. 1627.

Galileo was himself an outspoken advocate of the Copernican system, whose supporters he found invariably better informed than its opponents, until forced to recant by the Holy Office in 1633.

31. GALILEI, Galileo. *Dialogo*...Doue ne i congressi di quattro giornate si discorre sopra i due Massimi Sistemi Del Mondo Tolemaico, E Copernicano...

Florence, Gio: Batista Landini, 1632.

(Engraved title by Stephano della Bella.)

This work is essentially the "world system" promised earlier, and took the form of a dialogue between a proponent of Ptolemy and one of Copernicus with an objective observer as moderator. Although the discussion had no victor, the Copernican arguments were so strong and, contrarily, those for Ptolemy so weak (or even ludicrous) that the new astronomy was obviously favored. It was for this that Galileo was brought before the Inquisition and, after his abjuration, placed under arrest and forbidden to publish further.

He was a victim of a variety of pressures, among which was a growing Catholic opposition to the Copernican doctrine – or, at least, the Brunoesque positions which came to be associated with it. Actually, he and the Church were behind the times.

Long before Galileo recanted it, the original Copernican system had been revolutionized by Kepler, who had been exposed to it by the professor of astronomy at Tubingen, although apparently in private, for Michael Maestlin was then a teacher of Ptolemaic principles in print. More Pythagorean than Copernicus, Kepler might almost be considered a sun-worshiper. His first cosmological effort was an attempt to bind together the members of a Copernican solar system by means of the five regular solids. It was ingenious but not very successful.

32. KEPLER, Johann. *Prodromus Dissertationum cosmographicarum,* continens Mysterium Cosmographicum...

Tubingae, excudebat Georgius Gruppenbachius, 1596.

Although his own 1588 Epitome Astronomiae *expounded the "old" astronomical theories, Maestlin undertook to see this thoroughly "new" effort by his pupil through the press; indeed, he added to it, of his own accord, a new edition of Rheticus'* Narratio. *Although Kepler did not succeed, as he had hoped, in revealing the secret of the arrangement of the planetary orbits, he did demonstrate the possibility of showing harmony and proportion in the universe through the close commensurability of the Platonic figures, and, more important, he did set forth reasons for abandoning the Ptolemaic in favor of the Copernican system with great lucidity. Furthermore, the work contains the germ of many of his subsequently developed ideas.*

Kepler achieved significant fruit only when he applied his great mathematical skill to the observations of Brahe.

Having been willed the task of carrying out a reform of planetary theory by Tycho, Kepler set to work on the problem of Mars, the most intractable of the planets in all systems because of the great eccentricity of its orbit.

33. KEPLER, Johann. *Astronomical Manuscript* containing calculations on the latitude and longitude of certain astronomical bodies, in which Kepler mentions that Copernicus made similar observations.

Holograph. 4 pp. on 1 leaf.

Prior to Kepler's arrival, the work on Mars – the eccentricity of which was the subject of the earlier Ptolemaic and Copernican drawings – had been assigned to Longomontanus. Since the latter was making little progress, the task was given to the eager Kepler, who boasted that he would solve the problem of the Martian orbit in eight days. The eight days were destined to become nearly eight years. Though it cannot be said with any certainty that this example of Kepler's work belongs to that particular period, it is entirely possible that it does. Even if it does not, however, the manuscript does show Kepler laboring with the Copernican model ever before his mind.

He began, like all others, by attempting to locate its positions by combinations of circular motion. He was able, in this way, to approximate the positions observed by Tycho. His faith in the extreme accuracy of those observations was such, however, that he would not tolerate even small deviations. So, he abandoned circular motion and set out, as Ramus had proposed, to find a path that would correspond more closely to the data. In the process, he discovered the rule connecting the distance of Mars from the sun with its speed in its orbit. Indeed, this determination formed an essential part of his attack on the shape of the orbit. That shape turned out to be an ellipse. The rule for Mars' motion in it was that the planet moved in such a way that a line drawn from Mars to the sun sweeps out equal areas in equal times. Although he demonstrated these discoveries only in the case of Mars, Kepler's belief in the uniformity of the universe was such that he did not hesitate to generalize them into his first two laws of planetary motion.

34. KEPLER, Johann. *Astronomia Nova*... Sev Physica Coelestis, tradita commentariis De Motibus Stellae Martis, Ex Observationibus G. V. Tychonis Brahe: Jussu & Sumptibus Rvdolphi ij... [Prague or Heidelberg, E. Vogelin.] 1609.

Actually, Kepler did not accord his discoveries the status of "laws," but rather saw them as regularities or harmonies of nature. Whatever their appellation, however, they did create a new astronomy. It is for this reason that Dreyer stated that, next to this book there are in the history of astronomy "only two other works of equal importance, the book De Revolutionibus *of Copernicus and the* Principia *of Newton."*

As rewarding as these findings must have been, they had not achieved Kepler's basic goal of making manifest the harmony and beauty of the universe. Ten more years of almost incredible labor ensued. These efforts were crowned with success when he discovered that the squares of the periodic times of any two planets are to each other as the cubes of their mean distances from the sun. With his other laws, this proposition created an entirely new foundation for astronomical calculation. Copernicus had shown how to obtain the distances of the planets from observations, these distances being expressed relative to the unit supplied by the earth–sun distance. The values obtained, however, were unrelated by Copernicus. Kepler now showed them connected with each other by the periodic times, thus tying the entire system into an interrelated whole.

As might be expected, Kepler embedded this solution in a body of speculations concerning the "music of the spheres;" it is not for nothing that his third law is known as the harmonic law.

35. KEPLER, Johann. *Epitome Astronomiae Copernicanae,* Lib. i. ij. iij., de Doctrina Sphaerica. Lib. iv., Physica Coelestis. Lentiis ad Danubium, excudebat Johannes Plancus, 1618, 1620. Lib v., vi., vij., Doctrina Theorica.

Francofurti, Sumptibus Godefridi Tampachij, 1621.

Although he had intended to write a systematic treatise on astronomy, à la Ptolemy, in which he would do for the other planets what the previous work had done for Mars, various circumstances caused him to alter this plan and to produce, instead, this more elementary textbook. It was here that he extended his first two "laws" to the other members of the solar system, although he experienced great difficulties by virtue of his introduction of elliptic motion into lunar theory where he–like Tycho before, but independently of him–had discovered the annual equation of the moon. Interestingly, the pages on exhibit demonstrate his use of Galileo's discovery of the phases of Venus in support of Copernicanism.

36. KEPLER, Johann. *Harmonices Mundi Libri v,* quorum i. Geometricus, ij. Architectonicus, iij. Harmonicus, iv. Metaphysicus, Psychologicus et Astrologicus, v. Astronomicus et Metaphysicus, Appendix habet Comparationem huius Operis cum Harmonices Cl. Ptolemaei Libro iij. cumque Roberti de Fluctibus (Robert Fludd) Speculationibus Harmonicis...

Lincii Austriae, Sumptibus Godofredi Tampachi, 1619.

It has recently been demonstrated that a modern computer could have arrived at the relationship Kepler established in this work in less than one-half a minute. Kepler would probably not be dismayed at this, however, if for no other reason than the fact that such an inanimate machine would not be capable of enjoying the celestial harmonies which, first heard by Pythagoras, probably reverberated for the last time in the "mind's-ear" of a man whose mother was tried as a witch.

Many later writers have regretted his attention to such mysteries and analogies. And, it may well be that it was the amount of this material which kept such contemporaries as Galileo and Philip Lansberg, who published planetary tables founded on an epicyclic theory, from advancing beyond simple Copernicanism with Kepler.

37. LANSBERG, Philips van. *Opera Omnia...*
Middelburgi Zelandiae, 1663.
Includes his: *Tabulae Motuum Coelestum Perpetuae...*

Despite being calculated on out-of-date principles, Lansberg's tables enjoyed a considerable vogue for a period because they, unlike the next item on display, accurately predicted that the transit of Venus in 1639 would be visible in Europe. Originally published in 1632, the example shown here is in his later collected works.

To the great German mathematician, however, this material was vital rather than extraneous.

The importance of Kepler's discoveries can hardly be exaggerated. They did not represent simply another hypothesis by which tables of planetary motions could be constructed, although, of course, they did do that, allowing him to culminate his life's work with his superior *Rudolphine Tables.*

38. KEPLER, Johann. *Tabulae Rudolphinae, a Tychone...*
Ulm: Jonas Saur, 1627.
Presentation Copy, Signed. "Clarissimo Vivo D. Benjamini Ursino..."

Kepler himself designated this effort his principal astronomical work, for these tables were to put his theoretical hypotheses to the test. Despite the just-mentioned failure, they generally met that ordeal very well. Although not a great rarity in their usual form, the copy of the tables on display derives a considerable amount of uniqueness from the fact that it was a presentation copy, on the title page of which Kepler's signature may clearly be seen.

More fundamentally, however, they had found the actual orbit in which the planets travel through space. They had shown that those deviations beyond retrograde motion for the explanation of which epicycles and eccentrics had been invented, were simply the result of the fact that those orbits were elliptical. They had, in the words of Max Caspar, his greatest biographer, "substituted a dynamic system for the formal scheme of the earliest astronomers, the law of nature for mathematical rule, and causal explanation for the mathematical description of motion." Because of this, he concludes, Kepler "truly became the founder of celestial mechanics."

In one sense, these statements do claim too much for Kepler. He had accomplished a major shift in paradigms. Remnants of the old remained, however. Kepler still had to invoke "spirits" or a magnetic force from the sun–though this conformed to a definite mathematical formula–to account for the motion of the planets in the paths that he had established with such devoted labor.

If Galileo was behind Kepler in one respect, he was ahead of him in another, for where Kepler still assumed that a constantly acting force was necessary to explain motion, Galileo–taking up where the "impetus" workers had left off–was tending toward the modern doctrine of inertia which states that a body in motion will continue in a straight line until something intervenes to slow or deflect it. Although he had thus taken a decisive step in the direction of the needed new physics, Galileo also retained fragments of earlier paradigms: his vision was clouded by a predilection for circular motion.

39. GALILEI, Galileo. *Discorsi e Dimostrazioni Matematiche*, intorno a due nuove scienze attenenti alla mecanica et i movimenti locali...Con una appendice del centro di gravità d'alcuni solidi...

In Leida, appresso gli Elseviri, 1638.

Galileo had been tending toward inertia as early as the work that he wrote on motion (De Motu) *in 1604. And he actually employed the concept of circular inertia in his "letter on sunspots." But the experimental basis for his conclusion was provided only in this late study, which, because of the Inquisition's no publish order, had to be smuggled out of Italy for publication in the Dutch Republic.*

Indeed, the enunciation of the law of inertia in its modern form came from René Descartes, who approached the question from quite a different point of view.

Descartes was desirous of creating a unified scientific whole stemming from God. He required for this purpose only extension (matter) and movement. Granted this, his universe was to be so governed by law that no other form of it could be possible. It has been remarked, incidentally, that it was not mere chance that Descartes' concept of God as legislator of the universe should have been developed in France and only some fifty years after the treatment of sovereignty contained in the *De la République* of Jean Bodin, who elsewhere, interestingly, showed himself a typical late sixteenth century non-scientific opponent of Copernicanism from fear of novelty.

Basic to the development of Descartes' scientific structure was his principle of the conservation of momentum. His position was that God originally set matter in motion and that the universe subsequently maintained the same amount of motion. Just as this constancy followed from the very immutability of God, so inertia flowed as a deduction from it. Since the universe was conceived as totally packed with matter, the motions of its infinite parts did not require a force or a "spirit" for explanation – they were, instead, communicated by actual impact.

In addressing himself to the means by which this simple mechanistic conception could account for the facts of observation, Descartes elaborated his celebrated vortex theory. According to this hypothesis, what he called "first matter" formed whirlpools in the heavens. The planets were carried around in their particular eddy – in the center of which was the sun – by the matter with which they were in actual contact. These bodies could, thus, be thought of as purely mathematical, while such forces as gravity became, by definition mere manifestations of the laws of vortical motion.

40. DESCARTES, René. *Renati Des-Cartes Principia Philosophiae.* Amstelodami, Apud Ludovicum Elzevirium, 1644.

Descartes had been working on a "Treatise on the world" since 1630 when, in 1633, he learned of the Church's decree against Galileo's Copernicanism, which struck at the heart of his work. Although he felt he could maintain that the Inquisition's decision was not automatically an article of faith, he nevertheless proceeded with caution. And, the great machine that he finally advanced in the work on display reflected this in that, in view of Galileo's condemnation, it provided the immediate practical advantage of allowing Descartes to argue that since the earth was at rest in its surrounding medium it was unmoved, although it, together with the entire vortex, necessarily circled the sun. Specious perhaps, but terribly clever!

It was because so much of his system did depend upon definition that it was to prove untenable over a long period of time. Although alleging mathematical concern, Descartes in fact removed from mathematical consideration precisely those characteristics of the phenomenal world which Galileo had been struggling to express. Because of this and because the laws of vortical action were too difficult to allow any real precision in the picture of the machinery of the universe–precisely when quantification was becoming increasingly important–the Cartesian paradigm had to be undone if further progress were to take place. It remains only to say that–although wrong–the Cartesian system was a remarkable construct. It was the first truly comprehensive attempt to look at the world in a fundamentally new, mechanistic, and non-teleological way. Small wonder that in 1671 an obscure French physicist should observe that the entire period between Aristotle and Descartes had been barren so far as science was concerned. Indeed, Descartes became a kind of new Aristotle, and Cartesianism remained the basis for instruction in physics even in Newton's Cambridge until the second decade of the eighteenth century. But it was Newton who accomplished the undoing of Cartesianism and, if you want, the completion of the Copernican revolution.

41. ROHAULT, Jacques. *Traité de Physique.*

2 vols. in 1. Paris, veuve de Charles Saureux, 1671.

Although "obscure" from our point in time, Rohault was, in fact, the major expositor of Cartesian physics, none of the principles of which—systematically set forth in the treatise on display—was actually refuted in the seventeenth century. Still, the idea of gravitation was already in the air when Rohault printed this book; Newton, after all, had come close to his formulation in 1666. Others added bits and pieces throughout the 1670's and early '80's, though it remained for Newton to put everything together successfully. Interestingly, the case for Newtonianism steadily became a case against Cartesianism and was set forth, among other places, in a 1697 Latin translation of this work bearing Newtonian footnotes in refutation of the Cartesian text.

Extending the general laws of motion stemming from the work of Galileo, adding to them a better idea of force, and introducing the concept of mass, Newton was led to the conclusion that every particle of matter attracts every other particle with a force proportional to the mass of each, and inversely proportional to the square of the distance between them. He then applied this result, known as the law of universal gravitation, to the circumstances of the actual solar system, by then consisting, excluding Saturn's ring, of 17 bodies. Given the positions and motions of those bodies at any one time, Newton's problem was to calculate, on the basis of their mutual gravitation, their positions and motions at any other time; and then, of course, to show that the results agreed with observations.

Such a calculation would necessarily involve, among other quantities, the masses of the several bodies. These, of course, were not known, nor could they be directly determined. They could, however, be assumed. And if the assumptions were such as to bring about agreement between the results of calculation and those of observation, they could be taken as valid determinations. In the same way, the dimensions of the solar system and the shapes of its members could be modified in any manner not actually inconsistent with direct observation.

The general problem formulated in this fashion could be reduced to simpler ones, the greatest reduction of this sort resulting from the fact that the solar system is so constituted that each body's motion could be treated as determined *primarily* by one other body only; a planet, therefore, moving as if no other planet existed.

This problem of the motion of two mutually gravitating spheres was completely solved by Newton. It was shown, of course, to lead to Kepler's first two laws of planetary motion. Newton realized, however, that this was not the actual case. He knew that other bodies – and deviations from spherical form – did exert an effect, and that, therefore, each body in the solar system should be regarded as moving around some one body in an ellipse that was slightly disturbed by the actions of others. In this way he achieved an explanation of the remaining type of variation – namely, perturbed deviations – from regularity in planetary motions. By virtue both of that accomplishment and by mathematically defining – if never successfully explaining – the force which moved the planets, Newton may be said to have completed the revolution begun in astronomical theory by the Copernican insight and insistence that the earth is in motion and subject to the same laws as those governing other, similar planets. Moreover, since gravity touched interlopers as well as normal bodies, comets were brought within the explanatory framework.

42. NEWTON, Sir Isaac. *Philosophiae Naturalis Principia Mathematica* [two line title]...

Londini, Jussu Societatis Regiae ac Typis Josephi Streater... 1687.

The foregoing description, and previous comments, have sufficiently indicated the great significance of this work. One further point ought be made here, however, if for no other reason than its further vindication of the work of Copernicus. Thus, although one has previously emphasized Copernicus' conservatism and implied that the epicycles he retained were discredited and exterminated as a result of Kepler's work, that is not really true since some of them had remained as devices to account for such perturbed deviations as the annual equation of the moon. It was only with Newton's explanation of the latter that they vanished – absorbed into his mechanics as series of trigonometrical terms.

Cosmology and mathematical theory had been rejoined, with the important difference that the first now depended upon and was, in a sense, derived from the second. The horse–gravitational celestial mechanics–again pulled the cart–the Newtonian world picture.

Completed though it now was, the new astronomy of Copernicus was still not proved by direct observation. It seems fitting to close this brief treatment of Copernicanism with some indications of these later developments. Although the rotation of the earth on its axis had frequently been made the subject of experiment, a successful demonstration of it was not achieved until the early nineteenth century by Benzenberg and became generally accepted, because Benzenberg's effort was little known, only about fifty years later through the work of Foucault.

43. BENZENBERG, Johann Friedrich. *Versuch über das Gesetz des Falls,* über den Widerstand der Luft und über die Umdrehung der Erde, nebst der Geschichte aller früherer Versuche von Galilăi bis auf Guglielmini...

Dortmund, Malinckrodt, 1804.

Galileo failed in his effort in this direction. Newton thought that it could be done, but did not try to do so himself. Robert Hooke did in 1679, but his experiments were inconclusive, while those of Guglielmini more than a century later were very inaccurate. Benzenberg succeeded in determining the displacement toward the east of falling lead spheres, first in the tower of Hamburg's Michaelis Church in 1802, and, two years later, in a mine shaft in Schlebusch.

44. FOUCAULT, Jean Bernard Léon. *Sur Divers Signes Sensibles du Mouvement Diurne de la Terre.*

(In: "Comptes rendus des Seances de l'Académie des Sciences." Paris, 1851.)

One of the pioneers in astronomical photography, Foucault was led to experimentation with a conical pendulum to regulate the drive of a telescope to keep it continuously pointed at the object being photographed. Having noted the tendency of the pendulum to maintain its plane of vibration, he suspended a two-meter one in the cellar of his house and watched its swing grad-

ually turn "in the direction of the diurnal motion of the celestial sphere." After repeating the experiment with an 11 meter pendulum in the meridian hall of the Paris Observatory, he made the report to the Academy of Sciences on display here from the library of Lehigh University. Scaled up again thereafter and moved to the Panthéon, the experiment was soon being repeated all over the world and can be found in operation today in many observatories, planetaria, science museums, etc.

As to the earth's revolution around the sun, Roemer's discovery of the gradual propagation of light in 1675 had strongly supported it, while Bradley's 1728 explanation of the aberration of light demanded it.

45. ROEMER, Ole [or Olof]. *Demonstration touchant le mouvement de la lumière...*

(In: *Histoire* of the Academy of Sciences. Paris, 1730, Vol. x, p. 575.)

Galileo had eventually followed up his discovery of Jupiter's satellites with the preparation of tables of their motions which he hoped could be used for the determination of longitude. It was not until the later tables of Cassini, however, that this became a possibility by virtue of their ability to forecast the moments at which those moons would be eclipsed. Roemer, a young Danish astronomer studying that phenomenon in Paris, discovered that the intervals between successive eclipses were regularly less than predicted when Jupiter and the earth were approaching one another than when they were receding. He explained this by the supposition that, contrary to then accepted opinion, light travels through space at a finite though great speed which could be roughly estimated from the difference of intervals observed and the known rates of motion of the earth *and of Jupiter. Although first reported in a 1675 work by Cassini, and repeated in the* Journal des sçavans *the following year, the account on display is that in the later* Histoire *of the Academy of Sciences from the Lehigh library.*

46. BRADLEY, James. *Account of a new discovered motion of the fixed stars...*

(In: *Philosophical Transactions*. 1728, p. 637.)

Interestingly, Bradley's discovery of aberration resulted from an attempt to detect the parallactic displacement of stars which should result from the annual revolution of the earth about the sun. The shift that he in fact observed, however, was some three months out of skew with what that motion should have produced. The explanation that he finally seized upon and pub-

lished in the Philosophical Transactions *was that, given the finite velocity of light, the movement of the eye would always cause a difference between the real and the visible place of the object. Thus, although it occurred at different points in the earth's orbit from those where parallax would manifest itself, this phenomenon did call for an earthly orbit.*

The actual measurement of the parallactic shift of a star, however, had to wait until 1838, when Bessel's detection of the displacement of a fixed star placed the cement in a Copernican universe.

47. BESSEL, Friedrich Wilhelm. *Untersuchungen uber die Entfernung des 61 Sterns des Schwan.*

Konigsberg, 1838. (Rare author's offprint; published before the journal issue of *Astronomische Nachrichten*. Nos. 365–366, Dec. 1838–Jan. 1839 (?).

Like many astronomers before him, Bessel, who early performed a signal service for stellar studies by extracting a superior star catalogue from Bradley's Greenwich observations, evidenced a long and continuing interest in the subject of the parallax of the stars. But it was not until 1837 that he found the time to pursue observations for such equipped with an exquisite instrument and a new principle. The latter came into play in his choice of a test star, for he had decided to seek a near neighbor in space–and, thus, one with appreciable parallax–among the apparently swiftest-moving stars rather than among the brightest. Having drawn attention to the possibilities of 61 Cygni on that basis as early as 1812, he made known the results of his year of observations of it in this paper from the last month of 1838. Though its parallax of about a third of a second (0.3136") was small in amount, it was immense in implications.

That final piece of evidence in its favor fell into place only shortly after the religious opposition to Copernicanism had come to an official end. Although the resistance of the Roman Catholic Church had weakened in 1757, it did not totally disappear until the publication of the Index in 1835–the first edition since 1616 which did not contain the work of Copernicus. Thus it had required nearly 300 years for the shot fired by the canon of Frauenburg to impact upon all of the institutions of this moving earth.

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AUGUST 1973

ERRATA

Page 3, line 12, for *hypothecated* read *hypothesized.*

Page 20, the "Osiander Letter on verso of the title-page" listed with item 13 refers to item 12 (4th line from top).